

SECTION 601 – FUNDAMENTAL CONCEPTS OF PAVEMENT DESIGN AND EVALUATION.....	3
Sec. 601.01 Introduction .....	3
Sec. 601.02 Project Pavement Evaluations .....	4
SECTION 602 – FALLING WEIGHT DEFLECTOMETER TESTING AND ANALYSIS GUIDELINES .....	18
Sec. 602.01 Introduction .....	18
sec. 602.02 FWD Testing - Flexible Pavements .....	18
sec. 602.03 FWD Testing - Jointed Concrete Pavements .....	21
sec. 602.04 FWD Testing - Composite Pavements.....	26
sec. 602.05 FWD Testing - Continuously Reinforced Concrete Pavements .....	30
sec. 602.06 FWD Data Processing.....	34
SECTION 603 – PATCHING SURVEY GUIDELINES.....	36
Sec. 603.01 Patching Survey .....	36
SECTION 604 – GUIDELINES FOR USE OF THE 1993 AASHTO PAVEMENT DESIGN PROCEDURE .....	41
Sec. 604.01 Purpose.....	41
Sec. 604.02 Flexible Pavement Design.....	41
Sec. 604.03 Rigid Pavement Design.....	47
SECTION 605 – ASPHALT CONCRETE MIX SELECTION GUIDELINES .....	54
Sec. 605.01 Purpose Of Guidelines .....	54
Sec. 605.02 – Description Of Asphalt Concrete Mixes .....	54
Sec. 605.03 VDOT Asphalt Binders.....	58
Sec. 605.04 Asphalt Binder And Mix Selection – General Applications.....	59
Sec. 605.05 Asphalt Binder And Mix Selection – Specialized Locations.....	62
Sec. 605.06 Application Rates .....	62
Sec. 605.07 Typical Asphalt Base Mix Application Rates .....	63
SECTION 606 – PAVEMENT TYPE SELECTION PROCEDURES .....	65
Sec. 606.01 Introduction .....	65
Sec. 606.02 Pavement Type Selection.....	65
Sec. 606.03 Pavement Types .....	65
Sec. 606.04 Pavement Design.....	66
Sec. 606.05 Pavement Type Selection Procedures (PTSP) .....	66
Sec. 606.06 Alternate Bidding .....	69
Sec. 606.07 How To Use The Procedures .....	70
SECTION 607 – LIFE CYCLE COST ANALYSIS .....	73
Sec. 607.01 Executive Summary .....	73
Sec. 607.02 Introduction .....	74
Sec. 607.03 Economic Analysis Components .....	75

Sec. 607.04 Cost Factors.....	76
Sec. 607.05 Overview Of LCCA Pavement Options.....	78
Sec. 607.06 Asphalt Pavement Construction/Reconstruction.....	79
Sec. 607.07 Jointed Concrete Pavement Construction/Reconstruction With Tied Portland Cement Concrete Shoulders .....	83
Sec. 607.08 Jointed Plain Concrete Pavement Construction/Reconstruction With Wide Lane (14 Feet) And Asphalt Concrete Shoulders .....	85
Sec. 607.09 Continuously Reinforced Concrete Pavement Construction/Reconstruction With Tied Portland Cement Concrete Shoulders.....	86
Sec. 607.10 Continuously Reinforced Concrete Pavement Construction/Reconstruction With Wide Lanes (14 Feet) And Ac Shoulders .....	88
Sec. 607.11 LCCA For Major Rehabilitation Projects .....	90
Sec. 607.12 Unit Costs And Measures.....	90
Sec. 607.13 Interpretation Of Results .....	91

## **Chapter VI – PAVEMENT EVALUATION AND DESIGN**

### **SECTION 601 – FUNDAMENTAL CONCEPTS OF PAVEMENT DESIGN AND EVALUATION**

#### **SEC. 601.01 INTRODUCTION**

One of the State of Virginia's largest assets, if not the largest asset, is the highway network system. The Virginia Department of Transportation (VDOT) is responsible for maintaining the third largest roadway network in the United States encompassing over 53,000 miles. VDOT's Materials Division's Pavement Design and Evaluation (PD&E) Section is responsible for the review and comment on new and rehabilitated pavement structures around the state. PD&E assists the districts in the overall management of Virginia's highway construction program by providing guidance, technical assistance and training.

An important function in pavement management is project level analysis of existing roadway sections. Project level analysis is the inspection of existing pavements to determine the causes of deterioration and to assess the current condition. Once project level analysis has been conducted, then the most reliable pavement design can be performed. For new construction and rehabilitation projects, the combining of existing condition data, future traffic projections, soil subgrade properties and paving material properties will ensure a proper pavement design. This analysis and design should apply not only to pavement reconstruction and rehabilitation projects, but to routine and preventative maintenance projects as well.

The purpose of this document is to provide guidelines for VDOT's pavement engineers in conducting project evaluations and pavement designs on Major (Interstate, Primary, Urban and High-Volume Secondary) Roadways and Minor (Low-Volume Secondary and Sub-Division) Roadways. The amount of pavement evaluation required will be dependent on the scope of the project; the pavement design process will depend on the roadway classification (Interstate, Primary or Secondary). This document covers design considerations for routine maintenance, rehabilitation and construction activities performed by VDOT. However, it does not preclude from consideration new and innovative pavement techniques.

## **SEC. 601.02 PROJECT PAVEMENT EVALUATIONS**

Major Roadway project evaluation process is a two-step procedure: Step 1 – Preliminary Pavement Analysis and Design, Step 2 – Detailed Pavement Evaluation and Design. Major Roadways consist of Interstate, Major and Minor Arterial, and Major and Minor Collector routes. Step 1 occurs during the project-scoping phase of a construction-funded project being managed by the Location and Design Division. Step 2 occurs after the scoping phase during the Planning, Specifications and Estimating (detailed design) development.

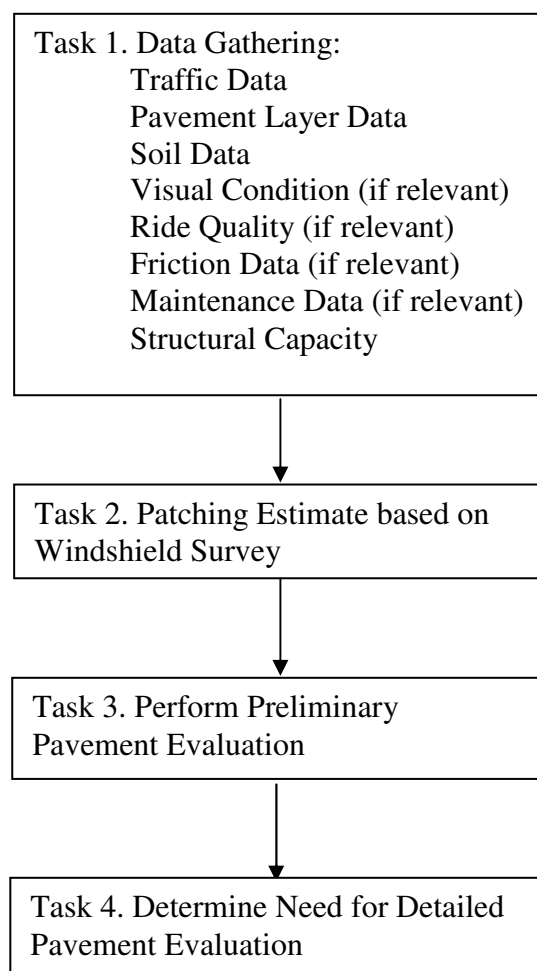
The details for these evaluations are provided in the following sections.

### **(a) Preliminary Pavement Evaluation**

Step 1 is the preliminary pavement analysis and design. This process will occur once the District Materials Engineer has been notified that a project requires a pavement design. Ideally, the Location and Design Section will notify the District Materials Engineer prior to establishing a preliminary construction estimate. With pavement items being a large percentage of the overall construction cost, a good initial estimate will aid L&D in requesting construction funds. At the preliminary evaluation and design phase of a project, the PD&E Section will provide technical assistance to the District Pavement Engineer. To conduct the preliminary pavement evaluation, the District Pavement Engineer should conduct 4 tasks. These tasks are:

- Task 1. Data Gathering
- Task 2. Field Data Collection
- Task 3. Preliminary Recommendation
- Task 4. Determine Need for Detailed Pavement Evaluation

Figure 1 shows the process flow for the preliminary pavement evaluations.



**Figure 1 - Preliminary Pavement Evaluation Process Flow**

### Task 1. Data Gathering

For construction projects where existing pavement may be utilized, data should be gathered prior to performing a preliminary evaluation. If available and relevant to the project, the Pavement Engineer should gather:

- Traffic Data (AADT, ESAL Factor, % Trucks, etc.),
- Pavement Layer Data (Materials, Thickness', Year Constructed)
- Soil Condition Data (Type and Strength),
- Visual Condition Data,
- Ride Quality Data,
- Structural Capacity Data,
- Friction Data, and
- Maintenance Data (including dates and types of rehabilitation).

Much of this data may be contained in HTRIS; however, the data must be validated prior to conducting the analysis. It is important to remember that for projects that include the widening of an existing pavement, realignment of a roadway (where a portion of the existing pavement is used), or other projects where the existing pavement is part of the final design, the existing pavement must be evaluated and addressed in the final pavement recommendation.

### Task 2. Patching Estimate From Windshield Survey

For a preliminary evaluation, minimal field data collection is required. The Pavement Engineer should perform a limited visual survey on the pavement surface and drainage structures (i.e. curb and gutter, ditches, underdrains).

Where the existing pavement may be utilized, proper patching of deteriorated pavement is necessary at the time of maintenance/rehabilitation. The Pavement Engineer should estimate the amount of full-depth and partial depth patching required by performing a windshield survey. Approximate areas of pavement experiencing alligator cracking, rutting and localized failures should be used to estimate patching types and quantities. Refer to SECTION 603 for guidance in determining patching type based on distresses observed.

Note:

Full-Depth Patches are defined as removing all Portland Cement Concrete (PCC) / AC material – surface mix, intermediate mix and base mix by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.

Partial Depth Patches are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

In addition, the Pavement Engineer should consider the pavement drainage conditions and their effects on the current pavement condition and potential rehabilitation alternatives. This will include, but not be limited to:

- Curb and gutter condition;
- Curb reveal;
- Shoulders;

Side ditches;  
Underdrains; and  
Medians.

Finally, the Pavement Engineer should note any other pertinent information related to the project that may affect the final pavement design. Examples are poor roadway geometry (excessive cross-slope, excessive crown, etc.), guardrail height, bridge clearances, etc. While the Pavement Engineer is not responsible for measuring or assessing these items, general knowledge of these items will assist in developing pavement options.

### Task 3. Preliminary Recommendation

Upon completion of the field data collection and data analysis, the Pavement Engineer will develop a preliminary pavement recommendation.

#### *Subtask 3.1. Data Analysis*

For each project, a minimal amount of data analysis should be required. The Pavement Engineer should:

Calculate the cumulative number of ESALS (if necessary) based on available traffic data;

Calculate the required structural capacity using the procedures given in SECTION 604;

Determine the preliminary pavement improvement or potential improvements (overlay, new construction, reconstruction, etc.).

This analysis should be conducted to ensure a good initial construction estimate as well as to inform the Location and Design Section of possible pavement requirements for the project.

#### *Subtask 3.2. Preliminary Pavement Report*

Once the data analysis is completed, the Pavement Engineer will prepare a preliminary pavement report. This report will document the project's description, pavement structure, traffic levels, surface condition, and recommended improvement or improvement options.

Based on the recommended improvement or improvement options, a cost estimate can be developed by the project manager. If several improvement options are available and the project meets the life cycle cost analysis (LCCA) requirements outlined in SECTION 607.02, then a LCCA should be performed.

### Task 4. Determine Need for Detailed Pavement Evaluation (Non-Construction Program Projects)

Once the preliminary pavement evaluation is complete, the Pavement Engineer must determine if the project requires a Detailed Pavement Evaluation. This task applies to projects not in the Six-Year Improvement Program (SYIP). Projects in the SYIP will be subject to a detailed pavement evaluation.

For routine maintenance activities a detailed project level analysis will not be required. These activities include:

Crack Sealing;  
AC Overlay (1.5") based on AASHTO Pavement Design (no additional structure is required, overlay required to improve ride or friction characteristics only);

AC Overlay (2.0") based on AASHTO Pavement Design (less than 5% of the pavement surface requires patching);  
Surface Treatment (less than 5% of the pavement surface requires patching); and  
Patching (less than 5% of the pavement surface requires patching).

For those projects that require more than 5% patching or require a structural capacity improvement based on the preliminary data analysis conducted in Subtask 3.1, then a Detailed Pavement Evaluation should be conducted.

**(b) Detailed Pavement Evaluation**

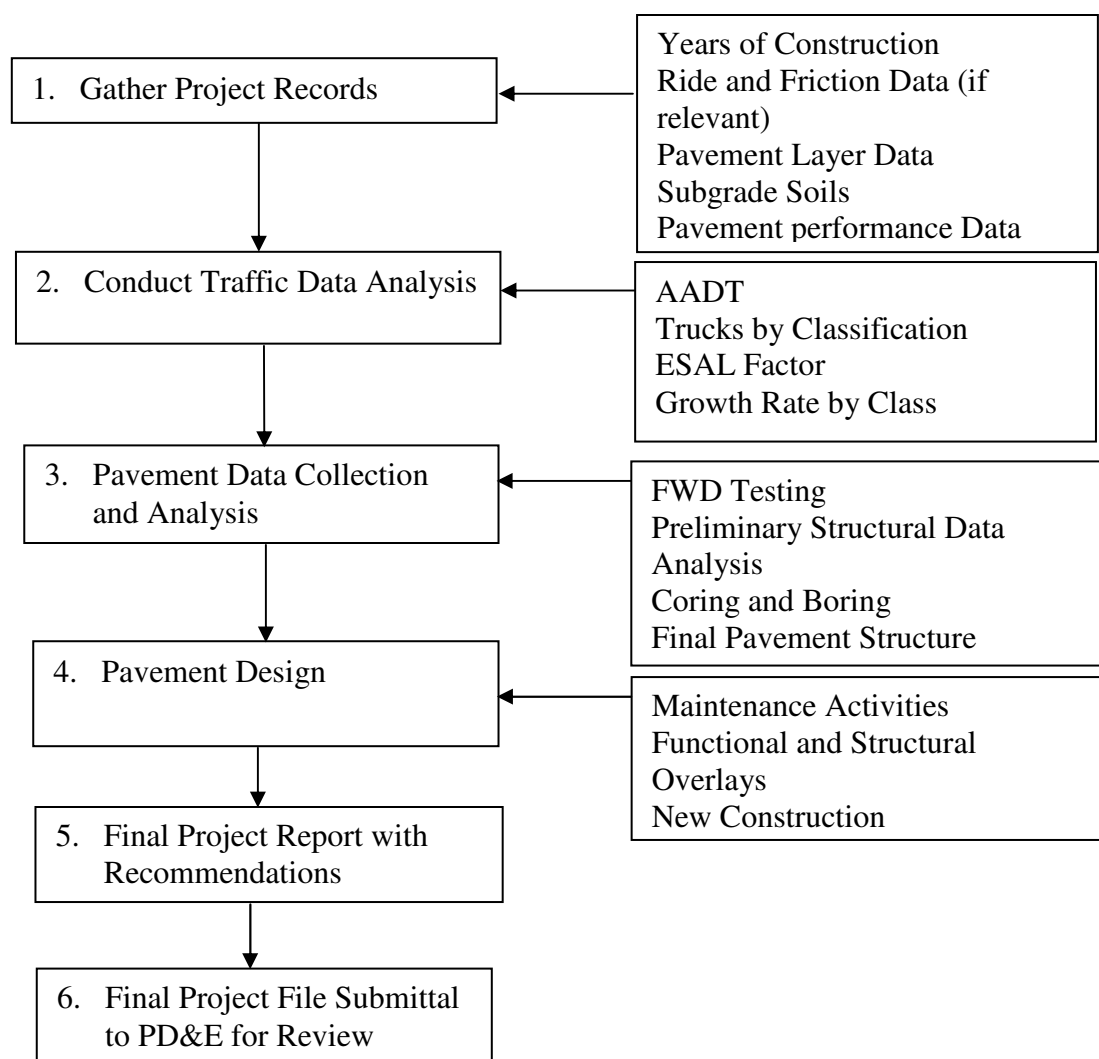
The detailed pavement evaluation will serve several purposes. First, the evaluation will refine the preliminary pavement recommendation. Second, the Pavement Engineer will be able to provide a better construction estimate to aid in allocating funds within the district. And third, the final pavement recommendation will aid the highway designer in developing construction documents (plans, specifications, etc.). This evaluation will help ensure proper improvements and designs to VDOT's assets.

To conduct a detailed pavement evaluation, the following tasks should be performed:

- Task 1. Records Review
- Task 2. Traffic Data Analysis
- Task 3. Pavement Data Collection and Analysis
- Task 4. Maintenance and Rehabilitation Design/New Design
- Task 5. Final Report
- Task 6. Project File Submittal to Pavement Design and Evaluation Section

Figure 2 shows the process flow for the detailed pavement evaluations.





**Figure 2 - Detailed Pavement Evaluation Process Flow**

#### Task 1. Records Review

As performed in the preliminary evaluation, the Pavement Engineer should conduct a record review to update and expand the data previously gathered. This review will concentrate on construction history, maintenance history, and pavement performance data (current and historical). For new construction projects, Task 1 can be omitted.

By reviewing “As-Built” construction plans and history information in HTRIS (if available), the following data should be collected:

- Years of Construction (original and resurfacing),
- Pavement Ride Quality (if relevant),
- Pavement Surface Friction (if relevant),
- Pavement Layer Materials, and
- Subgrade Soil Types and Strengths.
- Pavement Performance History (LDR, NDR, CCI), if available.

With use of the HTRIS, the Pavement Engineer should be able to obtain current pavement performance data and historical performance data, which will be beneficial in Task 4.

#### Task 2. Traffic Data Analysis

Unlike the preliminary pavement evaluation, a more detailed traffic data analysis is required. For the preliminary evaluation, the Pavement Engineer will gather available traffic data from the HTRIS and/or possibly District Traffic Engineering or Transportation Planning Sections. This data may only consist of average daily traffic counts, but may not contain information on the number and types of trucks using the roadway. For the detailed evaluation, more accurate data may be required depending on the information used for the preliminary evaluation and the preliminary pavement recommendation.

Traffic data to be collected should include:

- Average Annual Daily Traffic
- Number of Trucks by Classification
- ESAL Factor by Classification
- Traffic Growth Rate
- Truck Weights (if available from weigh station)

In the event some or all of this information is not available, the Pavement Engineer should request the Traffic Engineering Section to conduct at least a 12 hour traffic study and to provide an estimate of the daily (24-hour) traffic. This study should provide an estimate of the AADT, percent trucks, and classification of trucks using the roadway.

Once traffic data are collected, the Pavement Engineer will conduct a traffic analysis for the pavement design period. The purpose of this analysis will be to determine the required structural capacity for the pavement based on the expected/forecast traffic loading (cumulative ESALS). If the pavement requires an overlay, the Pavement Engineer will calculate the cumulative ESALS to date (years since last Major Rehabilitation) and ESALS to failure for the current pavement structure. The last Major Rehabilitation is generally defined as a pavement action where the net increase in pavement structure is at least 2.0" for flexible pavements and concrete pavement restoration (CPR) for rigid and composite pavements. The cumulative ESALS to date and ESALS to failure will be used to calculate the structural condition factor ( $C_x$ ) due to traffic. The structural condition factor is reported on a 0 to 1 scale and is used to determine the remaining life of the pavement (0 – 100%).

#### Task 3. Pavement Data Collection and Analysis

Under Task 3, the Pavement Engineer should perform the following data collection and analysis activities:

- Subtask 3.1. Falling Weight Deflectometer Testing
- Subtask 3.2. Preliminary Structural Data Analysis
- Subtask 3.3. Pavement Coring and Subgrade Boring
- Subtask 3.4. Final Pavement Structural Analysis
- Subtask 3.5. Patching Survey

*Subtask 3.1. Falling Weight Deflectometer Testing*

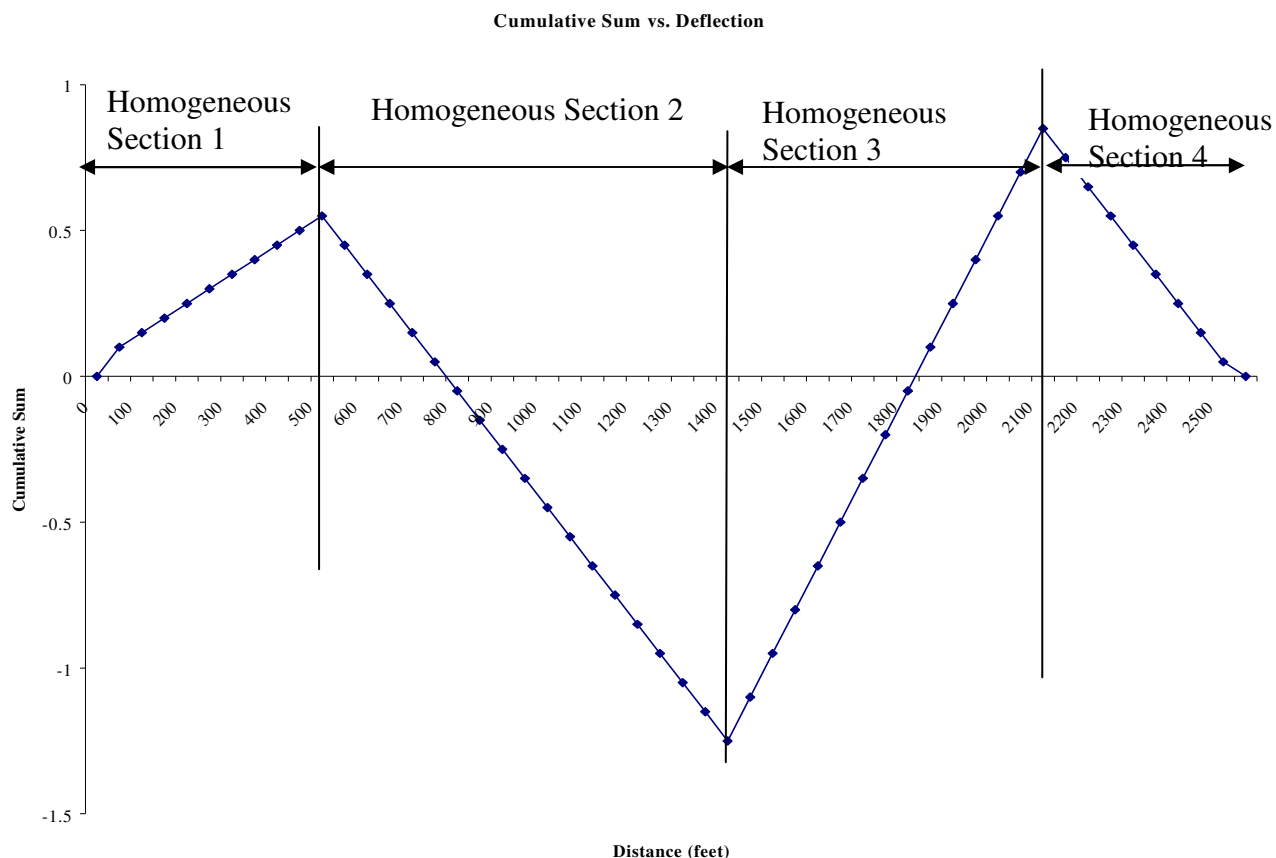
The purpose of FWD testing (Figure 3) is to assess the existing structural condition of the pavement and strength of the subgrade soils. FWD testing can be conducted on flexible, rigid and composite pavements. The amount and specifics of the testing for each type of pavement is contained in SECTION 602 of this document.



**Figure 3 - Falling Weight Deflectometer**

*Subtask 3.2. Preliminary Structural Data Analysis*

Upon completion of FWD testing, the Pavement Engineer will perform a section analysis of the data. This may be done by using the cumulative sums of deflection method outlined in Appendix J of the *1993 AASHTO Guide for the Design of Pavement Structures*. The Pavement Engineer will determine homogeneous sections of pavement and subgrade strength based upon deflection response as depicted in Figure 4. These homogeneous sections will be identified for pavement coring and possibly subgrade boring to determine the actual pavement structure. In addition, these sections will be used as analysis units in Task 4. A more detailed description of this process is contained in SECTION 602.



**Figure 4 - Example of Cumulative Sums Deflection**

#### *Subtask 3.3. Pavement Coring and Subgrade Boring*

Once pavement coring and boring locations has been identified in Subtask 3.2, the Pavement Engineer will arrange the coring and boring operations. For the pavement coring, the following should be recorded:

- pavement material types,
- thickness and
- visual condition.

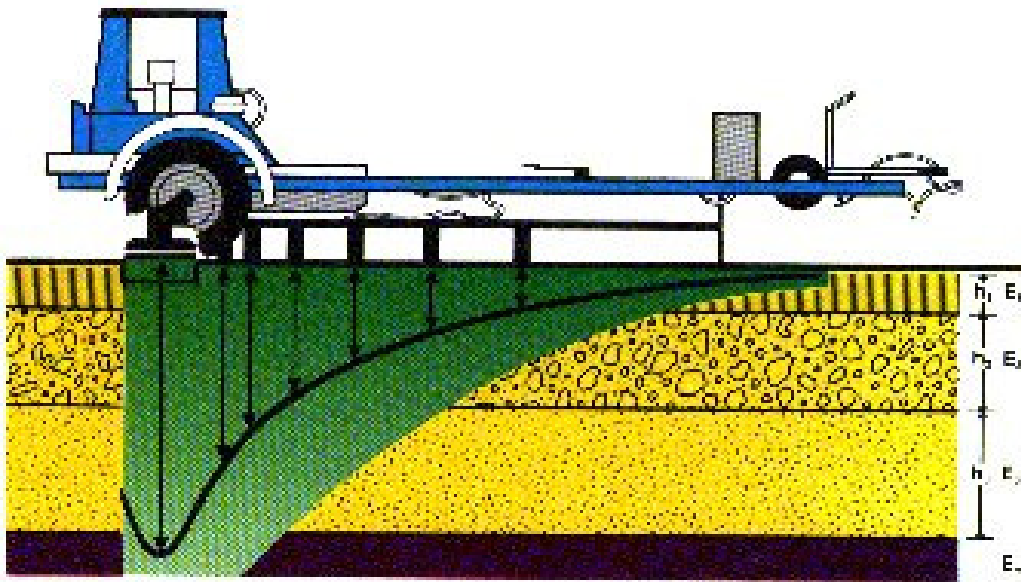
For the subgrade borings, a visual classification of the materials, moisture contents of the material, depth to water table, blow counts and retrieval of a bulk sample should be conducted. For investigating existing pavements, borings to a depth of 4 feet should be performed. Adequate material should be recovered from the borings for possible resilient modulus testing and laboratory classification. Please refer to other sections of the Manual of Instructions for more information on coring, boring and laboratory testing.

#### *Subtask 3.4. Final Pavement Structural Analysis*

Once the exact pavement structure and subgrade is known, the Pavement Engineer will conduct a final pavement structural analysis using the FWD data collected in Subtask 3.1.

Please refer to SECTION 602 for guidance on structural analysis. This analysis will be used to determine the existing structural capacity of the pavement. For flexible pavements, the Pavement Engineer will determine:

Effective Structural Number ( $SN_{eff}$ )  
 Layer Moduli and  
 Resilient Modulus of the Subgrade.



**Figure 5 – Deflection Basin Collected with Falling Weight Deflectometer**

For rigid pavements, the Pavement Engineer will determine:

Elastic Modulus of the PCC  
 Composite Modulus of Subgrade Reaction  
 Load Transfer at Cracks and Joints and  
 Potential for the Presence of Voids.

For composite pavements, the Pavement Engineer will determine:

Elastic Modulus of the PCC  
 Composite Modulus of Subgrade Reaction  
 Resilient Modulus of the Subgrade.  
 Load Transfer of Cracks and Joints and  
 Potential for the Presence of Voids.

These results will be used to design the future improvement of the roadway. SECTION 604 contains guidelines and recommendations for pavement analysis and designs.

#### *Subtask 3.5. Patching Survey*

For projects where the existing pavement will be incorporated into the final pavement design, the Pavement Engineer should determine the amount of full-depth and partial

depth patching required. For projects where the existing pavement will be demolished, this subtask can be omitted.

The amount of patching should be based on guidelines provided in SECTION 603 and the engineer's judgment. Please remember, if the total AC thickness is 8 inches and the final pavement recommendation calls for removing and replacing 2", then partial depth patches may not be required. Note:

Full-Depth Patches are defined as removing all PCC/AC material – surface, intermediate and base mixes, etc., by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.

Partial Depth Patches are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

Guidelines for determining patch locations and types for PCC and AC surfaces are contained in SECTION 603.

#### Task 4. Pavement Design

Upon completion of Task 3, the Pavement Engineer will develop a pavement design for the project. In general, a project will require one or more of the following:

- Maintenance Activities
- Functional Overlay
- Structural Overlay
- Full-depth Base Widening
- Reconstruction/New Construction

#### *Maintenance Activities*

For projects requiring a maintenance improvement, the Pavement Engineer will specify the maintenance to be performed. Maintenance activities may include, but not be limited to:

- Partial Depth Patches,
- Full Depth Patches,
- Crack Sealing,
- Surface Treatment (Slurry Seal, Micro surfacing, Chip Seal, etc.),
- Joint Sealing,
- Joint Cleaning, and
- Slab Stabilization.

The maintenance activity(s) designed should be based upon some of the following roadway attributes:

- Pavement Distress,
- Pavement Type,
- Maintenance Activity Performance
- Traffic Level and
- District Preferences (chip seal vs. slurry seal).

It will be the responsibility of the Pavement Engineer to investigate these attributes.

### *Functional and Structural Overlays*

For projects requiring a functional or structural improvement, the Pavement Engineer will perform pavement designs as well as specify any maintenance to be performed. The pavement designs are to be based on current AASHTO procedures. (Except Secondary Roads may use “The Pavement Design Guide for Subdivision and Secondary Roads in Virginia.” For higher-volume Secondary Roads, the use of AASHTO is encouraged.) The Pavement Engineer will use data collected in Task 3 to determine the current pavement condition and future requirements based on anticipated traffic. Where possible the Pavement Engineer should develop multiple alternatives for a project in order to perform life cycle cost comparisons. If the existing pavement may be removed, then the Pavement Engineer should refer to Section 606 on Pavement Type Selection. If the pavement is to remain in place, the Pavement Engineer should consider changing maintenance approaches (more vs. less patching), changing overlay thickness, changing milling thickness, changing materials, etc. For rigid pavements, concrete pavement restoration (CPR) may include joint/crack patching, grinding, dowel bar retrofit, etc. When CPR is considered by the pavement engineer, a 10-year design life should be used. The specifics on pavement design are contained in SECTION 604; the specifics on life cycle cost analysis are contained in Section 607.

### Task 5. Final Report

For each project, the Pavement Engineer will prepare a final report to document the technical approach and recommendations. This report will contain the following:

Section 1 - Specific Location of the Project

Section 2 - Existing Pavement Information (Rehab and Widening/Capacity Improvement Projects)

    Subsection 2.1 - Pavement Structure

    Subsection 2.2 - Pavement Condition based on Ride Data (IRI), Structural Capacity (FWD Testing Results), and Visual Condition (Distress Survey)

Section 3 - Soils Information based on Soils Report - Unsuitable Materials, Select Material, etc.

    Subsection 3.1 - Unsuitable Materials at Subgrade

    Subsection 3.2 - Unsuitable Materials in Cut Areas

    Subsection 3.3 - Shrinkage Factors for Excavation

    Subsection 3.4 - Slope Design

    Subsection 3.5 – Rock at Subgrade and in Cut Areas

Section 4 – Traffic Analysis Summary

    Subsection 4.1 – General Information (AADT for Design Year, Growth Rate, Truck Percentage, Truck Classes, ESAL Factor)

    Subsection 4.2 – Cumulative ESAL Computations

Section 5 – Pavement Recommendations

    Subsection 5.1 – Mainline Roadway

        General Description of Pavement Design

        Parameters/Assumptions used in Pavement Design (Mr, CBR, Design Life, Reliability, etc.)

        Description of Patching (Quantity required, locations, quantity to remove, Patching Material and Specifications)

Description of Pavement Design Cross Section with Notes  
Drainage Considerations (subsurface drainage – see Section 604)  
Shoulder Design Details (see Section 604)  
Subsection 5.2 – Connecting Roadways, Ramps, etc. (same as outlined above)  
Section 6 – Sources of Material

Not all report sections will be required for all projects. It is the responsibility of the Pavement Engineer to determine what sections are to be included in the final report. Much of this information will be contained in separate appendices attached to the report. This information may include:

*Detailed Structural and Functional Condition Data (Section 2)*  
*Detailed Soils Information (Section 3)*  
*Detailed Traffic Analysis (Section 4)*  
*Pavement Design Parameters (Section 5)*

Section 3 is not intended to replace the Soils Report, but summarize the information for the project designer(s).

The final recommendation will provide details on the materials to be used, material thickness, maintenance, etc. If necessary, the Pavement Engineer will provide any special provisions for construction and pavement cross sections. The main purpose of this report is to aid District Location and Design personnel in preparing project plans and contract documents.

Task 6. Project File Submittal to PD&E for Review and Comment

Once the District Pavement Engineer has obtained approval from the District Materials Engineer, the project file may be submitted to the Materials Division's Pavement Design and Evaluation Section for review and comment. Projects that have a construction estimate over \$2 million at time of Preliminary Field Inspection meeting should be submitted. As a quality assurance step, this review should be obtained prior to the incorporation of pavement designs in the final project plans.

Whether a project report is submitted or not to PD&E, all Districts should use the following Pavement Recommendation Project File Format for their own review. This format will aid PD&E in the review of the projects by providing the right information at the right time. Additionally, this will provide complete design information for projects when it is needed for future reference. As a minimum, if applicable to the project, the file will contain:

- Cover Memo
- Pavement Design/Rehabilitation Report with Appendices
- General Pavement Details
- Project Preliminary Plans
- Printouts from Pavement Design Software properly labeled
- Traffic Analysis
- Existing Pavement Condition Surveys (Applies to Rehab Projects and Widening/Capacity Improvement Projects)



Once received by PD&E, the proper reviews will be conducted and comments obtained. Then, the Materials Division will forward the pavement designs to the Location and Design Division's Administrator with a letter concurring or disagreeing with part or all of the recommendations. This letter will include carbon copies to the District Materials Engineer and others as specified by the District Pavement Engineer.

## **SECTION 602 – FALLING WEIGHT DEFLECTOMETER TESTING AND ANALYSIS GUIDELINES**

### **SEC. 602.01 INTRODUCTION**

One of the most difficult exercises for a pavement engineer is analyzing deflection data collected with a falling weight deflectometer. While FWDs have been in use for over 20 years, the methods to process the data are far from perfect. Engineers, educators and researchers are constantly trying to develop new analysis approaches that will provide data results that match field conditions with laboratory results.

Although most of the development has been in the field of pavement research, several software tools are available for production data processing and analysis. The purpose of this document is to provide guideline for engineers to follow when setting up FWD testing on a project and for analyzing results. Additional information on analyzing the testing results can be found in the document titled “MODTAG – User’s Manual and Technical Documentation.”

FWD data analysis is not an easy process, but with practice and experience engineers will be able to evaluate and determine how to use the FWD results.

### **SEC. 602.02 FWD TESTING - FLEXIBLE PAVEMENTS**

For flexible pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils. In addition to the structural capacity, the elastic modulus for the surface, base and subbase layers can be determined.

#### **(a) FWD Testing Pattern**

The FWD testing pattern selected for a project should be related to the project’s size and layout. The Pavement Engineer should consider the number of lanes to be tested, total length of the project, and any unusual circumstances that would require a change in the testing pattern.

##### **Project Layout**

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

- Pavement structure is different than the outside lane,
- More load related distress is present as compared to the outside lane, or
- Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, the FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

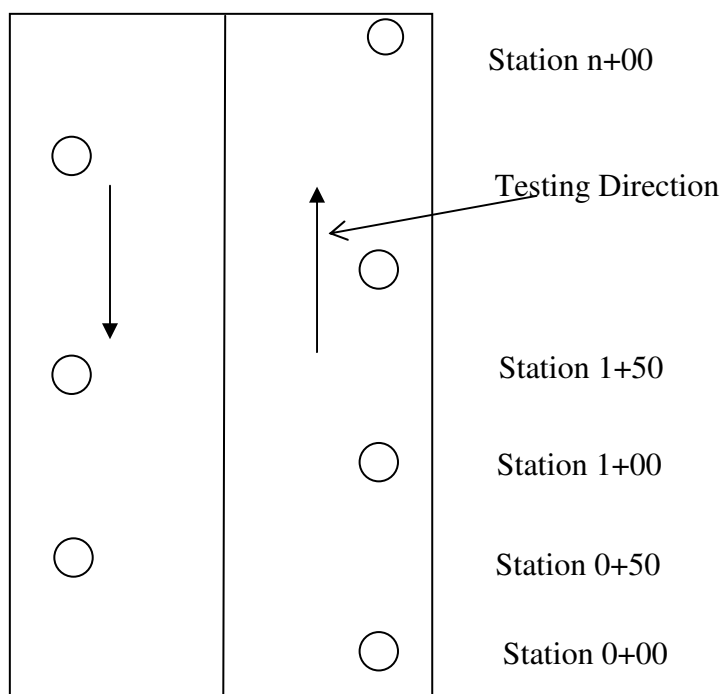
### Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 1 contains guidelines based on project size, test spacing, and estimated testing days. A testing day is defined as 200 locations tested.

Project Size (miles)	Test Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	75	½ Day
0.5 – 1.0	50	90	½ Day
1.0 – 2.0	50	175	1 Day
2.0 – 4.0	100	175	1 Day
4.0 – 8.0	150	200	1 to 1 ½ Days
> 8.0	200	>200	> 1 ½ Days

**Table 1 Flexible Pavement Test Spacing Guidelines**

For two or three lane bi-directional roadways not separated by a median, the testing should be staggered by one-half the test spacing. See Diagram 1 for clarification. For projects that are separated by a median, a staggered testing pattern is not required.



**Diagram 1 - Staggered Testing Pattern**

#### Basin Testing Location

For flexible pavements, FWD testing should be conducted in the wheel path closest to the nearest shoulder. This type of testing is known as basin testing since deflection measurements from all sensors may be used; refer to Figure 5. The purpose of this testing is to characterize the structural condition of the pavement where damage due to truck loading should be the greatest. For the outside lanes, testing should be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path.

#### (b) FWD Drop Sequence

Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the “seating drops” and the recorded impulse loads. Below is the recommended drop sequence for basin testing on flexible pavements:

- Two Seating Drops at 12,000 pounds
- Four Recorded Drops at 6,000 pounds
- Four Recorded Drops at 9,000 pounds
- Four Recorded Drops at 12,000 pounds
- Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in

measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer) is present, and if compaction/liquefaction is occurring in the subgrade.

#### **(c) FWD Sensor Spacing**

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the testing purpose (load transfer testing vs. basin testing). For basin testing on flexible pavements, the recommended spacing is given below:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

#### **(d) Surface Temperature Measurement**

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

### **SEC. 602.03 FWD TESTING - JOINTED CONCRETE PAVEMENTS**

For rigid pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement, estimate the strength of subgrade soils, assess load transfer at joints, and detect voids at joints. In addition to the structural capacity, the elastic modulus for the surface, base and sub-base layers can be determined.

#### **(a) FWD Testing Pattern**

The FWD testing pattern selected for a jointed concrete pavement project should be related to the project's layout, project size, and slab length. The Pavement Engineer should consider the number of lanes to be tested, total number of slabs, length of the project, and any unusual circumstances that would require a change in the testing pattern.

##### **Project Layout**

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one

direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

- Pavement structure is different than the outside lane,
- More load related distress is present as compared to the outside lane, or
- Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

#### Slab Length and Project Size

The number of jointed concrete slabs in a project will determine test spacing. For projects with short slab lengths, it may not be practical to test every slab (basin and joint testing). For projects with longer slab lengths, every slab may be tested.

In addition to slab length, the size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 2 contains guidelines based on project size, approximate slab length, test spacing, and estimated testing days. A testing day is defined as 175 locations tested (joints, corners and basins).

Project Size (miles)	Slab Length	Basin Test Spacing (no. of slabs)	Joint/Corner Spacing (no. of slabs)	Approximate Number of Tests	Testing Days
0 - 0.5	< 20'	Every 6th Slab	Every 2nd J/C	115	1 Day
	20' – 45'	Every Slab	Every J/C	175	1 Day
	> 45'	Every Slab	Every J/C	120	1 Day
0.5 – 1.0	< 20'	Every 9th Slab	Every 3rd J/C	180	1 Day
	20' – 45'	Every 2nd Slab	Every 2nd J/C	175	1 Day
	> 45'	Every Slab	Every J/C	300	1 ½ - 2 Days
1.0 – 2.0	< 20'	Every 12th Slab	Every 4th J/C	250	1 – 2 Days
	20' – 45'	Every 4th Slab	Every 2nd J/C	300	1 ½ - 2 Days
	> 45'	Every 2nd Slab	Every 2nd J/C	270	1 ½ - 2 Days
2.0 – 4.0	< 20'	Every 15th Slab	Every 5th J/C	380	1 ½ - 3 Days
	20' – 45'	Every 6th Slab	Every 4th J/C	380	1 ½ - 3 Days

Project Size (miles)	Slab Length	Basin Test Spacing (no. of slabs)	Joint/Corner Spacing (no. of slabs)	Approximate Number of Tests	Testing Days
	> 45'	Every 4th Slab	Every 2nd J/C	450	2 – 3 ½ Days
4.0 – 8.0	< 20'	Every 20th Slab	Every 10th J/C	220	1 ½ - 3 Days
	20' – 45'	Every 8th Slab	Every 4th J/C	470	2 ½ - 4 ½ Days
	> 45'	Every 6th Slab	Every 3rd J/C	590	2 ½ - 4 ½ Days
> 8.0	< 20'	Every 20th Slab	Every 10th J/C	450	3 Days
	20' – 45'	Every 10th Slab	Every 5th J/C	650	3 ½ - 4 Days
	> 45'	Every 8th Slab	Every 4th Slab	500	3 Days

**Table 2 Joint Concrete Pavement Test Spacing Guidelines**

#### Testing Location

For jointed concrete pavements, three types of FWD testing are generally conducted – basin, joint, and slab corner testing. Each test provides information on the structural integrity of the pavement.

#### *Basin Testing*

For jointed concrete pavements, basin testing should be conducted near the center of the slab (See Diagram 2). This testing provides information on the elastic modulus of the PCC and strength of base materials and subgrade soils.

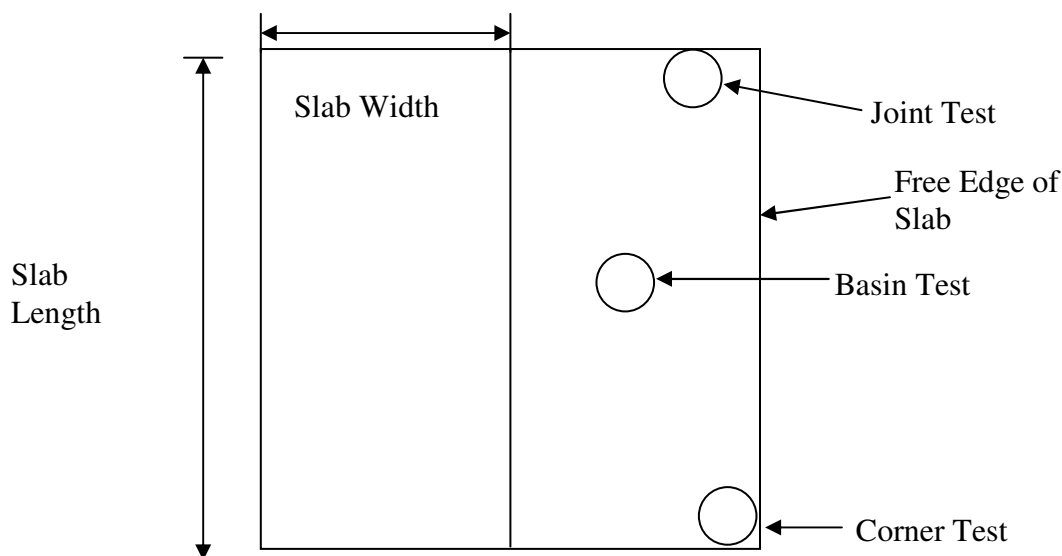
#### *Joint Testing*

For jointed concrete pavements, joint testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on joint load transfer – how well a joint, either through aggregate interlock and/or dowel bars, can transfer a wheel load from one slab to an adjacent slab.

#### *Corner Testing*

For jointed concrete pavements, corner testing should be conducted at the slab's free edge corner (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right corner edge of the slab. For inside lanes, testing should be conducted in the left corner edge of the slab. If more than two lanes exist, then the middle lanes should only be tested if pumping is suspected in the middle lanes. The Pavement Engineer will determine

if pumping is present and if testing should be conducted. Unless otherwise directed by the Pavement Engineer, corner testing shall be conducted on the leave side of the joint where voids are typically located. This testing provides information on the possibility for the presence of voids under a slab corner.



**Diagram 2 - JPC Testing Pattern**

### **(b) FWD Drop Sequence**

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the “seating drops” and the recorded impulse loads.

#### **Basin Testing**

Below is the recommended drop sequence for basin testing on jointed concrete pavements:

- Two Seating Drops at 12,000 pounds
- Four Recorded Drops at 6,000 pounds
- Four Recorded Drops at 9,000 pounds
- Four Recorded Drops at 12,000 pounds
- Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.



Joint Testing

Below is the recommended drop sequence for joint testing on jointed concrete pavements:

Two Seating Drops at 12,000 pounds  
Four Recorded Drops at 6,000 pounds  
Four Recorded Drops at 9,000 pounds  
Four Recorded Drops at 12,000 pounds  
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

Corner Testing

Below is the recommended drop sequence for corner testing on jointed concrete pavements:

Two Seating Drops at 12,000 pounds  
Four Recorded Drops at 9,000 pounds  
Four Recorded Drops at 12,000 pounds  
Four Recorded Drops at 16,000 pounds

In order to use the AASHTO procedure for the detection of voids, three different load levels are required; therefore, at each test location the FWD will need to perform 11 drops and record three sets of deflection and impulse load data

**(c) FWD Sensor Spacing**

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For jointed concrete pavements, three types of testing are performed – joint, corner and basin.

Basin Testing

For basin testing on jointed concrete pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

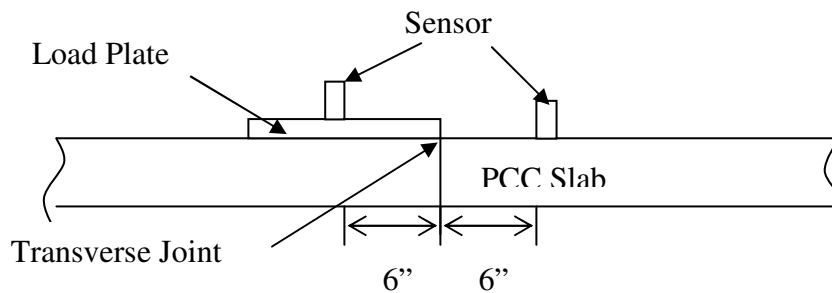
If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

Joint Testing

For joint testing on jointed concrete pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 3).



**Diagram 3 - Joint Load Transfer Testing Sensor Spacing**

**(d) Surface Temperature Measurement**

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

**SEC. 602.04 FWD TESTING - COMPOSITE PAVEMENTS**

For composite pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils as well as assess the load transfer at underlying joints. In addition to the structural capacity, the elastic modulus for the surface, base and subbase layers can be estimated.

**(a) FWD Testing Pattern**

The FWD testing pattern selected for a project should be related to the project's size and layout. The Pavement Engineer should consider the number of lanes to be tested, total length of the project, and any unusual circumstances that would require a change in the testing pattern. In addition, the AC overlay thickness should be considered. If the thickness is less than four inches, then the load transfer of the underlying PCC joints may be performed.

**Project Layout**

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one

direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

- Pavement structure is different than the outside lane,
- More load related distress is present as compared to the outside lane, or
- Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

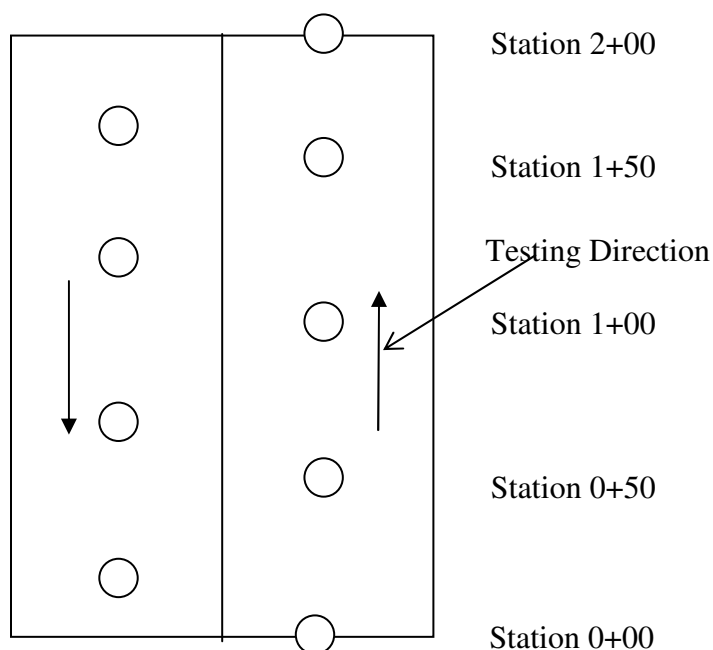
#### Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 3 contains guidelines based on project size, test spacing, and estimated testing days if load transfer testing is not performed. If load transfer testing is desired, then the appropriate spacing should be determined in the field. As a guideline, please refer to Joint/Corner Spacing column in Table 2. A testing day is defined as 200 locations tested.

Project Size (miles)	Test Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	75	½ day
0.5 – 1.0	50	90	½ Day
1.0 – 2.0	50	175	1 Day
2.0 – 4.0	100	175	1 Day
4.0 – 8.0	150	200	1 to 1 ½ Days
> 8.0	200	>200	> 1 ½ Days

**Table 3 Composite Pavement Test Spacing Guidelines**

For two or three lane bi-directional roadways not separated by a median, the testing should be staggered by one-half the test spacing. See Diagram 4 for clarification. For projects that are separated by a median, a staggered testing pattern is not required.



**Diagram 4 - Staggered Testing Pattern**

#### Testing Locations

For composite pavements, two types of FWD testing are generally conducted – basin and joint. Each test provides information on the structural integrity of the pavement.

#### *Basin Testing*

For composite pavements, basin testing should be conducted in the middle of the lane or near the center of the slab (See Diagram 4). This testing provides information on the elastic modulus of the AC, PCC and strength of base materials and subgrade soils.

#### *Joint Testing*

For composite pavements, joint testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on joint load transfer – how well a joint, either through aggregate interlock and/or dowel bars, can transfer a wheel load from one slab to an adjacent slab.

#### **FWD Drop Sequence**

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the “seating drops” and the recorded impulse loads.

Basin Testing

Below is the recommended drop sequence for basin testing on composite pavements:

Two Seating Drops at 12,000 pounds  
Four Recorded Drops at 6,000 pounds  
Four Recorded Drops at 9,000 pounds  
Four Recorded Drops at 12,000 pounds  
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.

Joint Testing

Below is the recommended drop sequence for joint testing on composite pavements:

Two Seating Drops at 12,000 pounds  
Four Recorded Drops at 6,000 pounds  
Four Recorded Drops at 9,000 pounds  
Four Recorded Drops at 12,000 pounds  
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

**(c) FWD Sensor Spacing**

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For composite pavements, two types of testing are performed – joint, and basin.

Basin Testing

For basin testing on composite pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

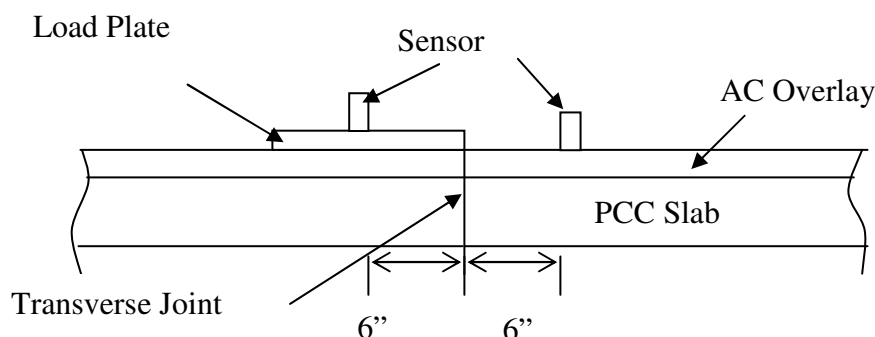
If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be removed.

Joint Testing

For joint testing on composite pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 5).



**Diagram 5 - Joint Load Transfer Testing Sensor Spacing**

#### **(d) Pavement Temperature Readings**

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach to determine the mid-depth pavement temperature is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. Using temperature correlation models such as the BELLS3 equation, the mid-depth AC material temperature can be estimated.

### **SEC. 602.05 FWD TESTING - CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS**

For rigid pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils. In addition to the structural capacity, the elastic modulus for the surface, base and sub-base layers can be determined.

#### **(a) FWD Testing Pattern**

The FWD testing pattern selected for a continuously reinforced concrete pavement project should be related to the project's layout and project size. The Pavement Engineer should consider the number of lanes to be tested, total number of slabs, length of the project, and any unusual circumstances that would require a change in the testing pattern.

### Project Layout

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

- Pavement structure is different than the outside lane,
- More load related distress is present as compared to the outside lane, or
- Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

### Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 4 contains guidelines based on project size, test spacing (basins and cracks), and estimated testing days. A testing day is defined as 175 locations tested (cracks and basins).

Project Size (miles)	Basin Test Spacing (feet)	Crack Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	25	150	1 Days
0.5 – 1.0	50	25	270	1 ½ Days
1.0 – 2.0	100	50	270	1 ½ - 2 Days
2.0 – 4.0	150	50	450	2 – 3 Days
4.0 – 8.0	150	75	650	2 ½ - 5 Days
> 8.0	200	150	680	4 Days

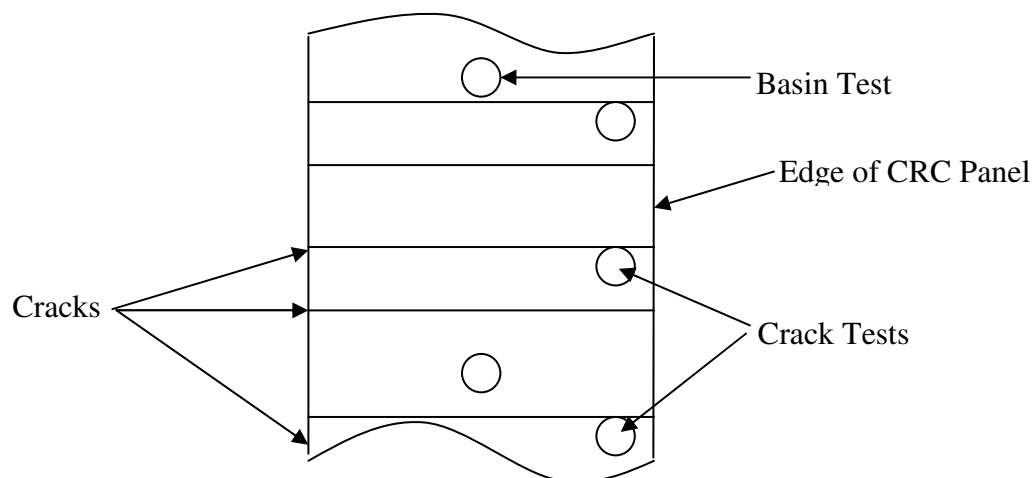
**Table 4 Continuously Reinforced Concrete Pavement Test Spacing Guidelines**

### Testing Location

For continuously reinforced concrete pavements, two types of FWD testing are generally conducted – basin and crack. Each test provides information on the structural integrity of the pavement.

#### *Basin Testing*

For continuously reinforced concrete pavements, basin testing should be conducted near the center of the panel (See Diagram 6). This testing provides information on the elastic modulus of the PCC and strength of base materials and subgrade soils.



**Diagram 6 - CRC Testing Pattern (one lane)**

#### *Crack Testing*

For continuously reinforced concrete pavements, crack testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 6). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on crack load transfer – how well a crack, either through aggregate interlock and/or steel reinforcement, can transfer a wheel load from one CRC panel to an adjacent panel.

#### **(b) FWD Drop Sequence**

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the “seating drops” and the recorded impulse loads.

#### Basin Testing

Below is the recommended drop sequence for basin testing on continuously reinforced concrete pavements:

- Two Seating Drops at 12,000 pounds
- Four Recorded Drops at 6,000 pounds
- Four Recorded Drops at 9,000 pounds
- Four Recorded Drops at 12,000 pounds
- Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in



measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.

#### Crack Testing

Below is the recommended drop sequence for crack testing on continuously reinforced concrete pavements:

Two Seating Drops at 12,000 pounds  
Four Recorded Drops at 6,000 pounds  
Four Recorded Drops at 9,000 pounds  
Four Recorded Drops at 12,000 pounds  
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

#### (c) FWD Sensor Spacing

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For continuously reinforced concrete pavements, two types of testing are performed – basin and crack.

#### Basin Testing

For basin testing on continuously reinforced concrete pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

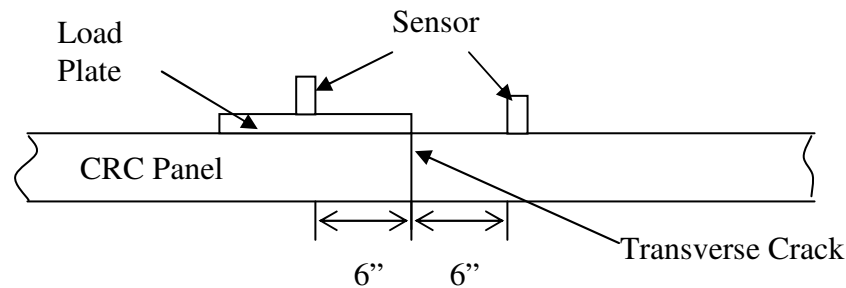
If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

#### Crack Testing

For crack testing on continuously reinforced concrete pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 7).



**Diagram 7 - Joint Load Transfer Testing Sensor Spacing**

**(d) Pavement Temperature Readings**

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

**SEC. 602.06 FWD DATA PROCESSING**

In order to process FWD data, many steps are required. These steps include gathering information on the pavement's surface condition, conducting a preliminary analysis on the deflection data, performing pavement coring and subgrade boring operations, processing of all the data collected, and analyzing, interpreting and reporting on the data results. Each one of these steps has numerous tasks associated with them. These steps are detailed in the following sections.

**(a) Pavement Surface Condition Survey**

Prior to collecting any FWD data, the engineer should conduct a detailed pavement condition and patching survey. These surveys will help the engineer establish possible problem areas with the pavement and set-up the appropriate FWD testing plan. Testing could be concentrated in specific areas while other areas could be avoided completely. The pavement condition survey should:

- Identify distress type, severity, extent and exact location,
- Identify patched areas and areas that will probably require patching before or during the rehabilitation project, and
- Use same linear referencing system as FWD data collection.

Once these data are collected, the engineer can plot the results on a straight-line diagram. This will be extremely beneficial when other data are collected and analyzed.

**(b) Preliminary Data Analysis**

Once FWD data are collected, it is important to perform a preliminary analysis on the deflection data. Please refer to the “MODTAG – Users Manual and Technical Documentation” for further instruction on preliminary data analysis.

**(c) Pavement Coring and Subgrade Boring**

In order to conduct an analysis of FWD data, the exact pavement structure must be known. For most roadways, the exact structure is not known; therefore, pavement coring is required. Also, while the engineer may know what type of subgrade soils exists in the project area, it cannot be assured without boring the subgrade and extracting samples. These materials collected in field can be analyzed in the lab, and the lab results used to validate FWD Data Analysis results.

For the materials above the subgrade, the coring and boring crew should record:

- Layer Materials – Asphalt, PCC, Granular, Cement Treated, etc
- Layer Thickness – Thickness for each different layer
- Layer Condition – AC material stripped, PCC deteriorated, granular material contaminated, etc.
- Material Types – For AC Materials, identify various layer types

For the subgrade soils, the crew should obtain adequate material in order to determine the following material properties in the lab:

- Soil classifications (gradations and Atterberg Limits)
- Natural moisture content
- Lab CBR
- Resilient modulus (undisturbed or remolded)

**(d) Full Data Processing**

Once pavement condition data and materials data are collected, then the engineer can perform the data processing. The type of data processing depends on 1) pavement type – flexible, rigid or composite, and 2) testing performed – basin, joint load transfer, or corner void. Please refer to the “MODTAG-Users Manual and Technical Documentation” for further instructions.

**(e) Data Analysis, Interpretation and Reporting**

Except for operating the FWD processing programs, the data analysis and interpretation is the most difficult portion. Once the analysis and interpretation is completed, then the results must be presented in such a manner to be used in the pavement design programs. Please refer to the “MODTAG-Users Manual and Technical Documentation” for further information.

## **SECTION 603 – PATCHING SURVEY GUIDELINES**

### **SEC. 603.01 PATCHING SURVEY**

The Pavement Engineer should estimate the amount of patching required for a project. The amount of patching should be recorded in square feet in the field and converted to square yards and tons in the office. While in the field, the Pavement Engineer should determine if a patch should be full-depth or partial depth. Below are the definitions for full-depth and partial depth patches:

**Full-Depth Patches** are defined as removing all PCC/AC material – surface, intermediate and base mixes, etc., by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.

**Partial Depth Patches** are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

#### **(a) Equipment and Supplies Needed**

To perform a patching survey, the following equipment and supplies are needed:

- Data Collection Sheets;
- Pencil;
- Clip Board;
- Hard Hat;
- Strobe Light;
- Vehicle;
- Map/Plan;
- Marking Paint
- Safety Vest; and
- Measuring Wheel.

#### **(b) Survey Procedure**

Below are suggested steps to perform a patching survey:

1. Prepare data collection sheets to record type of distress, location, and type of patch. By performing this activity in the office, effort in the field can be concentrated on identifying locations that require patching.
2. Once the sheets have been prepared, go to the field with the equipment and supplies outlined above.
3. Establish the beginning of the project (paving joint, bridge joint, intersection, etc.) and mark Station 0+00 if no other stationing has been established. This stationing should be used to reference all field collected data (visual condition, coring/boring, FWD, etc.).
4. Walk the project and locate the areas requiring patching, milling or requiring a comment. If traffic control is being provided, traverse the pavement to assess the pavement condition and determine if patching, milling, etc. should be performed. If traffic control is not provided, then assess the pavement condition and determine if patching, milling, etc. should be performed from the shoulder. VDOT work zone safety procedures should be observed at all times. If walking the pavement is not

possible due to safety or other reasons, the Pavement Engineer should request video logging of the pavement in order to perform a patching survey using a computer work station.

5. Once complete, the data can be entered into an EXCEL or similar spreadsheet to calculate the amount and type of patching, as well as milling quantities.

For the preliminary analysis, only approximate pavement areas are required. For detailed analysis, more attention must be given to locating the patching and milling limits.

In addition, the Pavement Engineer should consider the pavement drainage conditions. This should include, but not be limited to:

- Curb and gutter condition;
- Curb reveal;
- Shoulders;
- Underdrains;
- Side ditches; and
- Medians.

Finally, the Pavement Engineer should note any other pertinent information related to the project. Examples are poor roadway geometry, guardrail heights, bridge clearances, etc.

Guidelines for Determining Patch Types and Locations for AC Surfaces					
Distress Type	Severity Level	Milling (1" - 2")			Comments
		No	Yes		
			AC Material Thickness		
			> 6"	< 6"	
Alligator Cracking	1	None	None	None	
	2	Partial	Partial	Full	
	3	Full	Full	Full	
Rutting	1	None	None	None	If Subgrade problem, patch full depth to include replacing all materials and repairing subgrade
	2	Partial	None	None	
	3	Partial	Partial	Partial	
Linear Cracking	1	None	None	None	If crack is less than 1/2" wide and crack depth is less than 1/2 AC layer thickness, then crack fill. If the crack depth is greater than 1/2 AC layer thickness, then full depth patch.
	2	None	None	None	
	2	Partial	Partial	Partial	
Potholes/Failures/ Delaminations	N/A	Partial	None	None	Less than 6" in Diameter
	N/A	Partial	Partial	Full	Diameter is between 8" and 18"
	N/A	Full	Full	Full	Diameter is greater than 18"
Bumps/Sags	N/A	None	None	None	Causes low severity ride quality
	N/A	None	None	None	Causes medium severity ride quality
	N/A	Full	Full	Full	Causes high severity ride quality
Depression	N/A	None	None	None	Less than 1" deep
	N/A	Partial	None	None	Between 1" and 2" deep
	N/A	Full	Full	Full	Greater than 2" deep
Patches	N/A	None	None	None	Patch is in good condition and has little effect on ride quality

Guidelines for Determining Patch Types and Locations for AC Surfaces					
Distress Type	Severity Level	Milling (1" - 2")			Comments
		No	Yes		
			AC Material Thickness		
			> 6"	< 6"	
	N/A	Partial	Partial	Full	Patch is in fair condition (exhibiting Severity 1 LDR Distresses) or is effecting ride quality.
	N/A	Full	Full	Full	Patch is in poor condition (exhibiting Severity 2 or 3 LDR distresses).
Joint Reflection Cracking	1	None	None	None	Load transfer greater than 70%
	2	Partial	None	Partial	Load transfer greater than 70%, use joint tape if AC layer thickness is less than 6" thick and milling will be performed
	3	Partial	Partial	Partial	Load transfer greater than 70%; patch to top of PCC Surface
Joint Reflection Cracking	1	None	None	None	Load transfer less than 70%
	2	Full	Full	Full	Load transfer is less than 70%; potential to reduce to partial depth patching, if needed.
	3	Full	Full	Full	Load transfer less than 70%

Guidelines for Determining Patch Types and Locations for Concrete Pavement Surfaces				
Distress Type	Severity			Comments
	Low	Medium	High	
Blow-Up	Full	Full	Full	Consider grinding or undersealing the joint to remove fault. Consider grinding, undersealing or crack sealing for Low and Medium Severity. Replace in kind – Type I, II or IV Consider undersealing to correct Pumping Type II patch if punchout greater than 6' long Clean out spalled area and replace with AC
Corner Break	None	Full	Full	
Divided Slab	None	Full	Full	
Faulting	None	Full	Full	
Linear Cracking	None	None	Full	
Patching	None	**	Full	
Pumping	None	None	Full	
Punchout	Full	Full	Full	
Spalling	AC	AC	Full	

Full Depth Patches may be Type I, II or IV depending on pavement type and patching area. Refer to special provision on PCC patching

If LTE (Load Transfer Efficiency) < 70% - AC patch is not recommended (Use PCC patch).

If Mr subgrade is weak - PCC patch required.

If Pumping is evident - PCC patch required.



## **SECTION 604 – GUIDELINES FOR USE OF THE 1993 AASHTO PAVEMENT DESIGN PROCEDURE**

### **SEC. 604.01 PURPOSE**

These guidelines are intended to aid professional staff knowledgeable in the field of pavement design and evaluation. Persons using these guidelines are responsible for their proper use and application in concert with the AASHTO “Guide for Design of Pavement Structures – 1993”. The 1993 AASHTO Guide may be ordered by phone (800-231-3475) or via the internet (www.asshto.org). Virginia Department of Transportation and individuals associated with the development of this material cannot be held responsible for improper use or application.

### **SEC. 604.02 FLEXIBLE PAVEMENT DESIGN**

In a true flexible system, the pavement lacks the inherent structural stiffness to resist the bending action of the applied load. Therefore, it merely distributes stresses to the subgrade and relies on the shearing resistance of the soils for its performance. As a consequence, the thickness design of a flexible pavement is based upon the concept of limiting the stress applied to the subgrade so that, under the worst environmental conditions, the subgrade soils’ strength is not exceeded.

Generally, a flexible pavement is composed of a series of layers of granular and/or asphalt concrete materials, resting on compacted subgrade soil. The materials most effective in distributing the traffic loads to the subgrade are the base and subbase layers. The thickness of the asphaltic wearing surface may be relatively thin, such as with an asphalt surface treatment, in which case the granular materials provide the bulk of the pavement’s load transfer capacity.

As a flexible pavement achieves higher stiffness, it acquires a greater ability to resist the bending action of the load and consequently approaches the limiting condition of the rigid pavement definition. In fact, an asphaltic concrete pavement with high stiffness could easily behave as a rigid slab and exhibit distress (failure) manifestations similar to those of a concrete pavement. In this case, the limiting horizontal strain at the bottom of the asphalt concrete layer must be considered in the pavement design process.

#### **(a) Design Variables**

##### Pavement Design Life

Highway Classification	Initial Construction Design (Years)	Overlay Design (Years)
Interstate	30	12
Divided Primary Route	30	12
Undivided Primary Route	20	10
High Volume Secondary Route	20	10
Farm to Market Secondary Route	20	10

Highway Classification	Initial Construction Design (Years)	Overlay Design (Years)
Residential/Subdivision Street	20	10

### Traffic Factors

#### *Lane Distribution Factors*

Number of Lanes Per Direction	VDOT Value for Pavement Design (%)
1	100
2	90
3	70
4 or more	60

#### *Traffic Growth Rate Calculation*

$$GR = [AADT_f / AADT_i^{(1/(F-I))} - 1] \times 100$$

Where:

GR = Growth Rate (%)

AADT<sub>f</sub> = Average annual daily traffic for future year

AADT<sub>i</sub> = Average annual daily traffic for initial year

I = Initial year for AADT

F = Future year for AADT

#### *Future AADT Calculation*

If an AADT and growth rate is provided, then a future AADT can be calculated using the following equation:

$$AADT_f = AADT_i(1+GR/100)^{(F-I)}$$

Where:

GR = Growth Rate (%)

AADT<sub>f</sub> = Average annual daily traffic for future year

AADT<sub>i</sub> = Average annual daily traffic for initial year (year traffic data is provided)

I = Initial year for AADT

F = Future year for AADT

#### *ESAL Factors*

When no Weigh in Motion (WIM) or vehicle classification data are available to determine actual 18-kip Equivalent Single Axle Loads (ESAL) Factors, use the following values:

Vehicle Classification	ESAL Factor (ESALs/vehicle)
Cars/Passenger Vehicles	0.0002
Single Unit Trucks	0.46
Tractor Trailer Trucks	1.05

If traffic classification or WIM data are available, use Appendix D of the *1993 AASHTO Design Guide for Pavement Structures* to determine ESAL factors.

#### *ESAL Calculation*

For the ESAL calculation, use Compound Growth Factors. Assume the Growth in the ESAL Factor is 0%.

#### *Directional Split*

For the directional split of truck traffic on a route, assume a 50/50 distribution unless information from Traffic Engineering or other sources are provided.

#### Reliability

Highway Classification	VDOT Value for Pavement Design	
	Urban	Rural
Interstate	95	95
Divided Primary Route	90	90
Undivided Primary Route	90	85
High Volume Secondary Route	90	85
Farm to Market Secondary Route	85	75
Residential/Subdivision Street	75	70

#### Serviceability

Highway Classification	VDOT Value for Pavement Design	
	Initial	Terminal
Interstate	4.2	3.0
Divided Primary Route	4.2	2.9
Undivided Primary Route	4.2	2.8
High Volume Secondary Route	4.2	2.8
Farm to Market Secondary Route	4.0	2.5
Residential/Subdivision Street	4.0	2.0

#### Standard Deviation

For flexible pavements, the standard deviation of 0.49 shall be used.

#### Stage Construction

This is an option in the Darwin pavement design program, select Stage 1 construction; as it is extremely rare that the funds are committed to a 2nd stage of construction at a set time in the future.

**Material Information****Structural Layer Coefficients (New Design and Overlay)**

Material	Typical Value
SM-9.0	.44
SM-9.5	.44
SM-12.5	.44
IM-19.0	.44
BM-25.0	.44
SMA 9.5, SMA 12.5, SMA 19.0	.44
Graded Aggregate Base – 21A or 21B	.12
Cement Treated Aggregate Base	.20
Cement Treated Soil (i.e.- soil cement)	.18
Lime Treated Soil	.18
Rubblized Concrete	.18
Break and Seat/Crack and Seat Concrete	.25
Gravel	.10
Open Graded Drainage Layer – Bound	.10
Open Graded Drainage Layer – Unbound	0 – .10
All other soils and subgrade improvements	No Layer Coefficient

**AC Material Layer Thickness**

Material	Minimum Lift Thickness (in.)	Maximum Lift Thickness (in.)
SM-9.0	0.75	1.25
SM-9.5	1.25	1.5
SMA-9.5	1.25	1.5
SM-12.5	1.5	2
SMA-12.5	1.5	2
SMA-19.0	2	3
IM-19.0	2	3
BM-25.0	2.5	4
BM-37.5	3	6
Asphalt OGD	2	3
Cement OGD	4	4

**Drainage Coefficients (m)**

For most designs, use a value of 1.0. If the quality of drainage is known as well as the period of time the pavement is exposed to levels approaching saturation, then refer to Table 2.4 in the *1993 AASHTO Guide for the Design of Pavement Structures*.

**Design Subgrade Resilient Modulus**

Resilient Modulus values for a soil may be obtained from laboratory testing, correlations to other soil properties, and from FWD testing. While there are numerous sources, caution must be used when selecting a design resilient modulus. An analysis of all the soils data should be conducted prior to selecting a value.

*Laboratory Testing Results*

When laboratory testing is performed, an average Resilient Modulus (Mr) should not be used as the design Mr if the coefficient of variance (Cv) is greater than 10%. If the Cv is greater than 10%, then the Pavement Engineer should look at sections with similar Mr values and design those section based on that average Mr. If no sections clearly exist, then use the average Mr times 0.67 to obtain the design Mr. For those locations with an actual Mr less than the design Mr, then the Pavement Engineer should consider a separate design for that location or undercutting the area. More detailed procedures for using laboratory obtained Mr results will be contained in the future revision of this document.

*Laboratory Correlations*

If resilient modulus results are not available from laboratory testing, then use the following correlations:

For fine-grained soils with a soaked CBR less than 10, use the following equation to correlate CBR to resilient modulus (Mr):

$$\text{Design Mr (psi)} = 1,500 \times \text{CBR}$$

For non fine-grained soils with a soaked CBR greater than 10, use the following equation:

$$\text{Mr} = 3,000 \times \text{CBR}^{0.65}$$

Typical values for fine-grained soils are 2,000 to 10,000 psi.

Typical values for coarse-grained soils are 10,000 to 20,000 psi.

*FWD Testing Results*

When FWD testing is conducted and the backcalculated resilient modulus is determined, use the following equation:

$$\text{Design Mr} = C \times \text{Backcalculated Mr}$$

$$\text{Where } C = 0.33$$

*Selecting Appropriate Mr Value*

The design of flexible pavements is extremely sensitive to the design Mr value. The engineer must select the appropriate Mr value to ensure the pavement is not under or over designed. When no laboratory or FWD results are available, the engineer should use the Mr results based on the correlation to the CBR values. If results from FWD testing are available, then the engineer should use these results. CBR data can be used to validate the FWD results; material with a high CBR should have a high resilient modulus; material with a low CBR should have a low resilient modulus. If laboratory results exist and represent all of the soils to be encountered on the project, then these results should be used. If the results do not cover the entire project, then FWD results and laboratory correlations should supplement the laboratory results.

For all pavement designs, if the Design Mr is greater than 15,000 psi, then use a Design Mr value of 15,000 psi. This will prevent the over estimation of the subgrade strength which would lead to a potential pavement underdesign.

#### Shoulder Design

Typically, paved shoulders have a pavement structural capacity less than the mainline; however, this is dependent on the roadway. For Interstate routes, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure. A full-depth shoulder (same design as the mainline pavement) is also recommended for other high-volume non-interstate routes that are likely to be widened within the life of the mainline pavement.

Where a full-depth shoulder is not necessary, the shoulder's pavement structure should be based on 2.5% of the design ESALs (minimum) for the project following the AASHTO pavement design methodology. A minimum of two AC layers must be designed for the shoulder in order to provide edge support for the mainline pavement structure. The AC layers must be placed on an aggregate or cement stabilized aggregate layer, not directly on subgrade, to provide adequate support and drainage for the shoulder and mainline pavement structures. To help ensure positive subsurface drainage, the total pavement depth of the shoulder should be equal to the mainline structure (i.e. mainline pavement structure thickness above the subgrade is 20 inches, shoulder pavement structure thickness above the subgrade is 20 inches).

#### Drainage Considerations

The presence of water within the pavement structure has a detrimental effect on the pavement performance under anticipated traffic loads. The following are guidelines to minimize these effects:

Standard UD-2 underdrains and outlets are required on all raised medians. UD-2 underdrains are intended to intercept water that may seep onto the pavement surface at the curb/pavement joint and create a safety hazard. Additionally, UD-2 underdrains can prevent water infiltration through or under the pavement structure. Refer to the current VDOT Road and Bridge Standards for installation details.

When Aggregate Base Material, Type I, Size #21-B is used as an untreated base or subbase, it shall be connected to a longitudinal pavement drain (UD-4) with outlets or day lighted (to the face of the ditch) to provide for positive lateral drainage on all roadways with a design ADT of 1,000 vehicles per day or greater. For super-elevated roadways where day lighting is used, only the lower/down side of the aggregate layer should be extended to the face of the ditch. (Refer to the current VDOT Road and Bridge Standards for installation details.) Other drainage layers can also be used. When the design ADT is less than a 1,000 vehicles per day, the Engineer must assess the

potential for the presence of water and determine if sub-surface drainage provisions should be made.

When Aggregate Base Material, Size #21-A is used as an untreated base or subbase material, it should not be used to remove subsurface water by connecting it to a longitudinal underdrain.

Undercutting, transverse drains, stabilization, and special design surface and subsurface drainage installations should be considered whenever necessary to minimize the adverse impacts of subsurface water on the stability and strength of the pavement structure. Standard CD-1 and CD-2 should be considered for use with all types of unstabilized aggregates, independent of the traffic levels.

For roadways with a design ADT of 20,000 vehicles per day or greater, a stabilized drainage layer should be considered, placed on not less than 6 inches of stabilized aggregate material and connected to a UD-4 edge drain. Factors that may influence the selection of OGD include constructability issues involving maintenance of traffic (e.g. multiple traffic shifts to complete pavement, etc.), numerous entrances that have to be maintained during construction, numerous intersecting streets, etc.

For additional information see Report Number FHWA-TS-80-224, Highway Sub-Drainage Design from the US Department of Transportation, Federal Highway Administration.

### **SEC. 604.03 RIGID PAVEMENT DESIGN**

In a rigid pavement system, the pavement layer(s) is composed of materials of high rigidity and high elastic moduli which distributes a low level of stress over a wide area of the subgrade soil. Consequently, the major factor considered in the thickness design of rigid pavements is the structural strength of the pavement layers(s); i.e. – the concrete itself. Rigid pavements are classified into jointed and continuously reinforced. A jointed plain concrete pavement is an unreinforced pavement structure with joints at certain designated intervals to compensate for expansion and contraction forces and thermally induced stresses. Continuously reinforced concrete pavements, on the other hand, have been designed with sufficient reinforcement to eliminate the need for joints.

#### **Design Variables**

##### Pavement Design Life

Highway Classification	Initial Construction Design (Years)	AC Overlay Design (Years)	PCC Overlay Design (Years)
Interstate	30	10	30
Divided Primary Route	30	10	30
Undivided Primary Route	30	10	30
High Volume Secondary Route	30	10	30

Standard Deviation

For rigid pavements, a standard deviation of 0.39 shall be used.

Traffic Factors*Lane Distribution Factors*

Number of Lanes Per Direction	VDOT Value for Pavement Design (%)
1	100
2	90
3	70
4 or more	60

*Traffic Growth Rate Calculation*

$$GR = [(AADT_f / AADT_i)^{(1/(F-I))} - 1] \times 100$$

Where:

GR = Growth Rate (%)

AADT<sub>f</sub> = Average annual daily traffic for future year

AADT<sub>i</sub> = Average annual daily traffic for initial year

I = Initial year for AADT

F = Future year for AADT

*Future ADT Calculation*

If an AADT and growth rate is provided, then a future AADT can be calculated using the following equation:

$$AADT_f = AADT_i (1 + GR/100)^{(F-I)}$$

Where:

GR = Growth Rate (%)

AADT<sub>f</sub> = Average annual daily traffic for future year

AADT<sub>i</sub> = Average annual daily traffic for initial year (year traffic data is provided)

I = Initial year for AADT

F = Future year for AADT

*ESAL Factors*

When no Weigh in Motion (WIM) or vehicle classification data are available to determine actual 18-kip Equivalent Single Axle Loads (ESAL) Factors, use the following values:

Vehicle Classification	ESAL Factor (ESALs/Vehicle)
Cars/Passenger Vehicles	0.0003
Single Unit Trucks	0.59



Vehicle Classification	ESAL Factor (ESALs/Vehicle)
Tractor Trailer Trucks	1.59

*ESAL Calculation*

For the ESAL Calculation, use Compound Growth Factors. Assume Truck Growth ESAL Factor is 0%.

*Directional Split*

For the directional split of truck traffic on a route, assume a 50/50 distribution unless information from Traffic Engineering or other sources are provided.

Reliability

Highway Classification	VDOT Value for Pavement Design (%)	
	Urban	Rural
Interstate	95	95
Divided Primary Route	90	90
Undivided Primary Route	90	85
High Volume Secondary Route	90	85

Serviceability

Highway Classification	VDOT Value for Pavement Design	
	Initial	Terminal
Interstate	4.5	3.0
Divided Primary Route	4.5	2.9
Undivided Primary Route	4.5	2.8
High Volume Secondary Route	4.5	2.8

**Material Information**28-Day Mean PCC Modulus of Rupture (psi)

Typical Range – 600 to 800      VDOT Value for Pavement Design – 650

Use default value if actual value is not available. Where possible, use value base on historical data.

28-Day Mean PCC Modulus of Elasticity (psi)

Typical Range – 3,000,000 to 8,000,000      VDOT Value for Pavement Design – 5,000,000

Use default value if actual value is not available. Where possible, use value base on historical data.

Mean Effective k-value (psi/inch)

Typical Range – 50 to 500      VDOT Value for Pavement Design – 250

If the subgrade resilient modulus is known or obtained from correlation with CBR testing, then use the following equation:

$$k\text{-value} = M_r / 19.4$$

Caution must be used when selecting a design k-value based on resilient modulus and CBR. An analysis of all the soils data should be conducted prior to selecting a value. An average Resilient Modulus ( $M_r$ ) should not be used as the design  $M_r$  if the coefficient of variance ( $C_v$ ) is greater than 10%. If the  $C_v$  is greater than 10%, then the Pavement Engineer should look at sections with similar  $M_r$  values and design those section based on that average  $M_r$ . If no sections clearly exist, then use the average  $M_r$  times 67% to obtain the design  $M_r$ . For those locations with an actual  $M_r$  less than the design  $M_r$ , then the Pavement Engineer should consider a separate design for that location or undercutting the area.

If the k-value is obtained from backcalculation, then use this value.

If the k-value (based on backcalculation or subgrade resilient modulus) is larger than 500, then use 500 as the design value.

#### Subdrainage Coefficient

For most designs, use a value of 1.0. If the quality of drainage is known as well as the period of time the pavement is exposed to levels approaching saturation, then refer to Table 2.4 in the *1993 AASHTO Guide for the Design of Pavement Structures*.

#### Load Transfer Factors

##### *New Pavement Designs and Unbonded PCC Overlays with Load Transfer Devices*

Pavement Type	VDOT Value for Design	
	Asphalt Shoulder	Tied PCC Shoulder or Wide Lane
Jointed Plain	3.2	2.7
Continuously Reinforced	3.0	2.6

##### *Overlays Designs on Existing Pavements*

For AC overlays on existing PCC pavements and bonded PCC overlays, determine the appropriate J-Factor based on the load transfer efficiency determined from joint/crack testing.

Pavement Type	Load Transfer Efficiency	Design J-Factor
Jointed Plain	> 70%	3.2
	50 – 70%	3.5
	< 50%	4.0
Jointed Reinforced	> 70%	3.2
	50 – 70%	3.5
	< 50%	4.0
Continuously Reinforced		2.4 (working cracks repaired with CRCP)

### Shoulder Design

Typically, paved shoulders have a pavement structural capacity less than the mainline; however, this is dependent on the roadway. For Interstate routes, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure. A full-depth shoulder (same design as the mainline pavement) is also recommended for other high-volume non-interstate routes that are likely to be widened within the life of the mainline pavement.

Two types of shoulders are designed for Portland cement concrete highways – full-width concrete shoulders, narrow-width concrete section with an asphalt concrete extension, or an asphalt shoulder. For full-width concrete shoulders, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure.

A narrow-width concrete section with an asphalt concrete extension shoulder is constructed when a wide concrete lane (14 feet) is part of the mainline pavement. Twelve feet of the fourteen-foot wide slab is part of the outside travel lane, the remaining two feet is striped and designated as part of the shoulder. The two-foot section of concrete has the same structure as the twelve-foot section; therefore, no separate pavement design is necessary. For the asphalt concrete portion of the shoulder and other asphalt concrete shoulders not located on Interstates or high-volume routes, the shoulder's pavement structure should be based on 2.5% of the design ESALs (minimum) for the project following the AASHTO pavement design methodology. A minimum of two AC layers must be designed for the shoulder. The AC layers must be placed on an aggregate or cement stabilized aggregate layer, not directly on subgrade, to provide adequate support and drainage for the shoulder structure. To help ensure positive subsurface drainage, the total pavement depth of the shoulder should be equal to the mainline structure (i.e. mainline pavement structure thickness above the subgrade is 20 inches, shoulder pavement structure thickness above the subgrade is 20 inches). When the asphalt shoulder is constructed on an Interstate or high-volume roadway, the depth of the asphalt layers shall be the same as the depth of the Portland Cement Concrete slab.

### Drainage Considerations

The presence of water within the pavement structure has a detrimental effect on the pavement performance under anticipated traffic loads. The following are guidelines to minimize these effects:

Standard UD-2 underdrains and outlets are required on all raised medians. UD-2 underdrains are intended to intercept water that may seep onto the pavement surface at the curb/pavement joint and create a safety hazard. Additionally, UD-2 underdrains can prevent water infiltration through or under the pavement structure. Refer to the current VDOT Road and Bridge Standards for installation details.

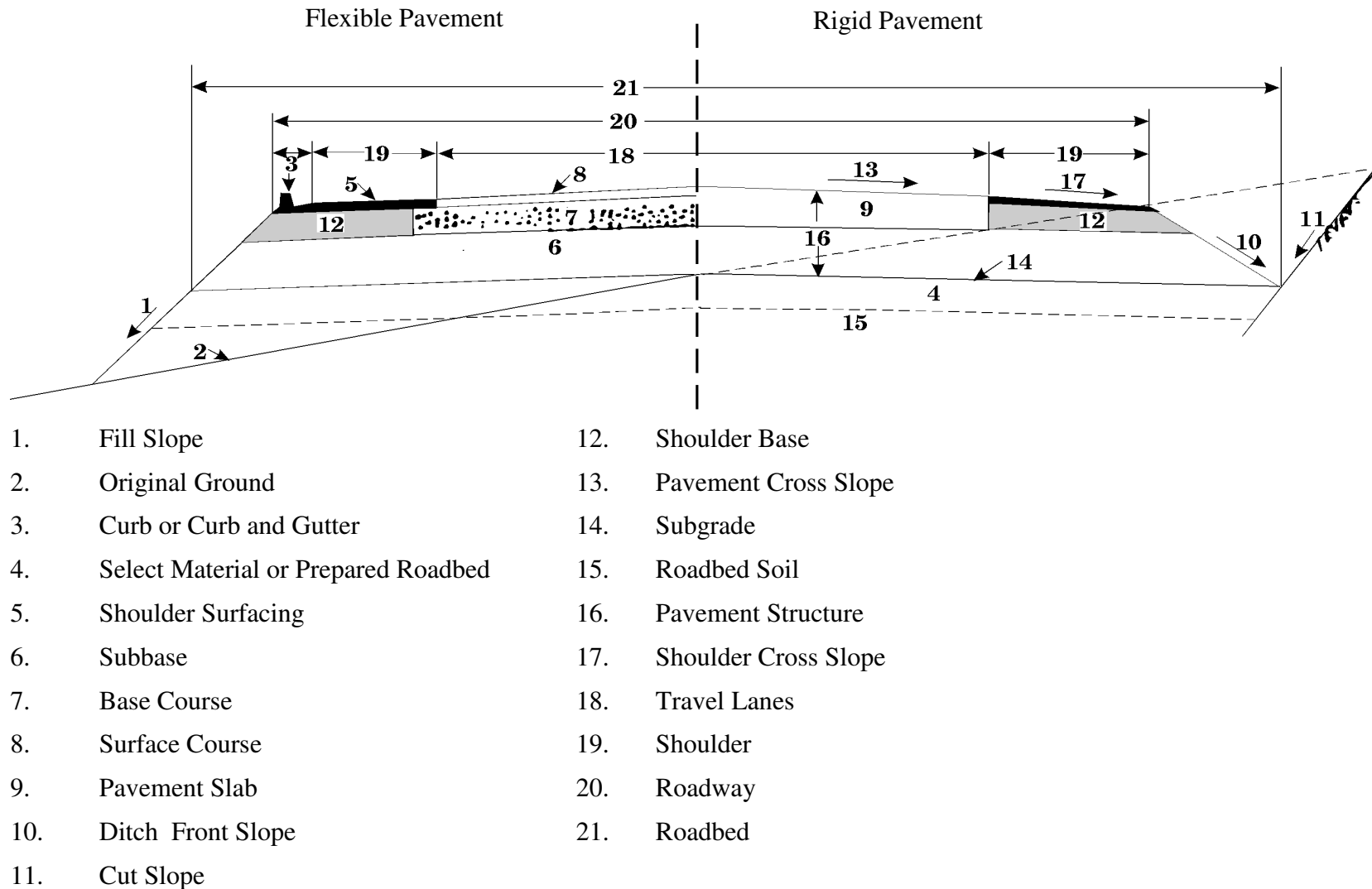
When Aggregate Base Material, Type I, Size #21-B is used as an untreated base or subbase, it shall be connected to a longitudinal pavement drain (UD-4) with outlets or day lighted (to the face of the ditch) to provide for positive lateral drainage on all roadways with a design ADT of 1,000 vehicles per day or greater. For super-elevated roadways where day-lighting is used, only the lower/down side of the aggregate layer should be extended to the face of the ditch. (Refer to the current VDOT Road and Bridge Standards for installation details.) Other drainage layers can also be used. When the design ADT is less than a 1,000 vehicles per day, the Engineer must assess the potential for the presence of water and determine if sub-surface drainage provisions should be made.

When Aggregate Base Material, Size #21-A is used as an untreated base or subbase material, it should not be used to remove subsurface water by connecting it to a longitudinal underdrain.

Undercutting, transverse drains, stabilization, and special design surface and subsurface drainage installations should be considered whenever necessary to minimize the adverse impacts of subsurface water on the stability and strength of the pavement structure. Standard CD-1 and CD-2 should be considered for use with all types of unstabilized aggregates, independent of the traffic levels.

For roadways with a design ADT of 20,000 vehicles per day or greater, a stabilized drainage layer should be considered, placed on not less than 6 inches of stabilized aggregate material and connected to a UD-4 edge drain. Factors that may influence the selection of OGD include constructability issues involving maintenance of traffic (e.g. multiple traffic shifts to complete pavement, etc.), numerous entrances that have to be maintained during construction, numerous intersecting streets, etc.

For additional information see Report Number FHWA-TS-80-224, Highway Sub-Drainage Design from the US Department of Transportation, Federal Highway Administration.



**Diagram 8 – Pavement Definitions**

## **SECTION 605 – ASPHALT CONCRETE MIX SELECTION GUIDELINES**

### **SEC. 605.01 PURPOSE OF GUIDELINES**

The guidelines provided herein are intended to aide the user in recommending mix types for asphalt overlays of flexible and rigid pavement, and new construction based on specific traffic and environmental conditions expected. These guidelines should be used as part of, or in conjunction with an engineering analysis of the pavement section. These guidelines are not intended to address pavement distress mechanisms, structural inadequacy of the pavement, existing pavement defects or other types of pavement deficiencies. It is the responsibility of the user to conduct an analysis/evaluation of the existing or expected pavement conditions prior to using this guide. Failure to do so could significantly affect the performance and service life of the materials and mixes selected.

These guidelines are applicable to VDOT projects. While the guidelines could be used for non-VDOT work with similar conditions, experience and engineering judgment should be exercised for such application.

These guidelines indicate the general highway conditions under which each mix should be used. Generally, a single mix type is used for all lanes in a single direction of a roadway. The asphalt binder type ESAL (Equivalent Single Axle load) range is based on an expected service life and is used in conjunction with the mix type's nominal maximum aggregate size in this guide. Traffic speed, vehicle types and volume should also be considered in the selection of a mix type. These considerations may warrant the use of a stiffer binder. Experience and judgment should be used in selecting the appropriate mixes to be used. Each District may implement a simple guide chart to eliminate those mixes that are not needed in their area.

### **SEC. 605.02 – DESCRIPTION OF ASPHALT CONCRETE MIXES**

Numerous asphalt mixes are used in Virginia. These mixes are designed to perform different functions within the pavement structure. Mixes vary based on nominal maximum aggregate size, aggregate gradation, asphalt binder content and other variables just to name a few. The following sections describe common asphalt mixes used in Virginia.

#### **(a) Dense Graded Mixes**

Dense graded mixes, also known as SUPERPAVE™, are asphalt mixes with a uniform distribution of aggregate sizes along the maximum density line. These mixes can be “fine” or “coarse” graded depending on whether the aggregate gradations are above or below the maximum density line. Dense graded mixes are identified based on the nominal maximum aggregate size. The nominal maximum aggregate size is defined as one sieve size larger than the first sieve to retain more than 10 percent aggregate as shown in the design range specified in Section 211.03, Table II-13 of the Road and Bridge Specifications. [It is important to note that while Virginia uses US Customary

units for constructing projects, asphalt mixes are identified based on the metric sieve equivalent (i.e. 9.5mm, 12.5mm, 19.0mm and 25.0mm).] Three different families of dense graded mixes are used in Virginia – surface, intermediate and base. A description of each family and the associated asphalt mix(s) are provided in the following section.

#### (1) Surface Mixes

Surface mixes serve as both functional and structural layers of the pavement structure. Surface mixes are directly exposed to traffic and the environment. They must provide a smooth, stable, safe (i.e. skid resistance) riding surface, and promote surface water drainage. In addition, they serve to prevent the entrance of excessive quantities of water into the underlying HMA layers, bases and subgrade. The surface layer normally contains the highest quality materials. In most instances, only one surface mix lift will be placed on a project. VDOT has three predominant dense graded surface mixes. Surface mixes are given the SM-XY.Z designation in contracts, specifications and special provisions where SM stands for surface mix and XY.Z denotes the nominal maximum aggregate size.

**SM-9.0** This mix is a ‘fine’ (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 inch (25 mm) thickness. This mix is generally used in subdivisions and low volume pavements with little or no heavy vehicle traffic (trucks, buses) as a final riding surface. This mix should never be placed directly on aggregate base material; it is recommended to be placed on a minimum of 2 inches (50 mm) of a larger nominal maximum aggregate surface, intermediate or base mix.

**SM-9.5** This mix is a ‘fine’ to ‘medium’ (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 ½ inches (40 mm) thickness. SM-9.5 mixes usually result in low water permeability values. This mix tends to be less susceptible to segregation than the SM-12.5 mix type described below. **SM-9.5 surface mixes can be considered the desired surface mix and are recommended for most final surface applications.**

**SM-12.5** This mix is a ‘medium’ to ‘coarse’ (½ inch (12.5 mm) nominal maximum aggregate size) surface mix generally placed at 2 inches (50 mm) thickness. Depending on the aggregate gradation, this mix is more suited for roadways that need additional structural capacity to handle traffic loads. This mix tends to have higher permeability values when compared to a SM-9.5.

#### (2) Intermediate Mix

The intermediate mix, sometimes called binder course, consists of one or more lifts of structural asphalt concrete placed below the surface layer. Its purpose is to distribute traffic loads so that stresses transmitted to the pavement foundation will not result in permanent deformation of that layer. Additionally, it facilitates the construction of the surface layer. Designed with larger aggregates, the intermediate layer is intended to provide resistance to rutting and to intercept top-down fatigue cracking. In most instances, only one intermediate mix lift will be used on a project. Intermediate mixes are given the IM-XY.Z designation in contracts, specifications and special provisions

where IM stands for intermediate mix and XY.Z denote the nominal maximum aggregate size.

**IM-19.0** This mix is a ‘coarse’ (3/4 inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. This mix can handle public traffic during construction for an extended period of time and allows for later application of a surface mix to provide a final wearing surface. In certain cases where structure is of a prime concern or traffic loadings are extreme, this mixture may be designated as a **SM-19.0** mixture and used as a final surface course, which requires a non-polishing aggregate when used as the final surface.

### (3) Base Mix

As the name implies, the base mix is the base asphalt layer for the pavement structure. Its major function is to provide the principal support of the pavement structure. The base mix uses the largest aggregate particles to provide resistance to rutting and to bottom-up fatigue cracking. Unlike surface mixes, more than one lift of base mix may be placed on a project to obtain the designed base layer thickness. Base mixes are given the BM-XY.Z designation in contracts, specifications and special provisions where BM stands for base mix and XY.Z denotes the nominal maximum aggregate size.

**BM-25.0** This mix is a 1 inch (25.0 mm) nominal maximum aggregate size mix generally placed at 3 inches (75 mm) or greater thickness. Depending on the aggregate gradations and placement procedures, this base does not usually require placement of an intermediate course to provide a platform for placement of a smooth wearing surface. Public traffic should not be permitted on this material for extended periods of time without restrictions.

### (b) Gap Graded Mixes

Gap graded mixes, are asphalt mixes with a non-uniform distribution of aggregate sizes. Stone Matrix Asphalt (SMA) is the only gap graded mix in Virginia. These mixes contain aggregates retained on the upper and lower sieves, but with little aggregate retained on the middle sieves. As with dense graded mixes, gap graded mixes (SMA) are identified based on the nominal maximum aggregate size. Two families of gap graded mixes are used in Virginia – surface and intermediate.

**SMA** is composed of a gap-graded aggregate that maximizes rutting resistance and durability with a stable stone-on-stone skeleton held together by a rich mixture of asphalt binder (specified PG grading), filler and stabilizing agents such as fibers. This mix is for use on heavy to extreme heavy traffic volume routes where the expected higher cost can be justified with improved performance over other mixes. SMAs are recommended for placements of a minimum of 5,000 tons and only in heavy traffic conditions due to their higher cost and special considerations in their design, production, and placement.

A description of each family and the associated asphalt mix(s) are provided in the following section. All gap graded mixes are given the designation SMA-XY.Z(binder type) in contracts, specifications and special provisions where SMA stands for stone



matrix asphalt, XY.Z denotes the nominal maximum aggregate size, and (binder type) denotes the binder to be used.

(1) Surface Mixes

VDOT has two SMA surface mixes.

**SMA-9.5** This mix is a ‘fine’ to ‘medium’ (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 ½ inches (40 mm) thickness. SMA 9.5 surface mix is recommended for final surface applications on high traffic volume and high truck volume routes.

**SMA-12.5** This mix is a ‘medium’ (½ inch (12.5 mm) nominal maximum aggregate size) surface mix generally placed at 2 inches (50 mm) thickness. SMA 12.5 surface mix is recommended for final surface applications on high traffic volume and high truck volume routes.

(2) Intermediate Mix

In most instances, only one intermediate mix lift will be used on a project. When rigid pavement is overlaid, more than one intermediate mix lift may be used.

**SMA-19.0** This mix is a ‘medium’ to ‘coarse’ (¾ inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. SMA 19.0 mixes are recommended for intermediate applications on high traffic volume and high truck volume routes.

(3) Base Mix

VDOT does not have any SMA Base Mix designation. If a base mix is desired for use with SMA, use a dense graded Base mix.

(c) Specialty Mixes

While the vast majority of asphalt placed in Virginia is either dense graded or gap graded, VDOT does use some specialty mixes. These mixes are designed to provide specific functions in the pavement structure. Below is a description of two mixes used in Virginia.

**Thin Hot Mix Asphalt Overlay (THMACO)** This mix is a ‘fine’ to ‘medium’ (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 3/4 inch (19 mm) thickness. THMACO is a gap graded hot mix asphalt applied atop a polymer-modified emulsion membrane and it is used for final surface applications as a functional overlay on flexible and rigid pavements. THMACO is primarily used for pavement preservation.

**Open Graded Drainage Layer (OGDL)** is a ‘medium’ (¾ inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. This mix has very little fine aggregate material to allow for the movement of water. It is used as

part of a pavement drainage system. Guidelines on use of OGD L can be found in Section 604.

### **SEC. 605.03 VDOT ASPHALT BINDERS**

As with the asphalt mixes, VDOT typically uses letters to designate asphalt binders in contracts, specifications and special provisions. For dense graded mixes, asphalt binder designations A, D and E are used. Mix stiffness generally increases from 'A' to 'E', with 'A' being the softest. For gap graded asphalt concrete, no letter designation is used in contracts, specifications and special provisions. In the specifications and special provisions for specialty mixes, the asphalt binder is declared. The following sections defined each asphalt binder.

#### **(a) Dense Graded Mix Binder Letter Designations**

**'A'** - The 'A' designation corresponds with a Performance Graded (PG) asphalt binder of PG 64-22. Surface asphalt mix types using the 'A' binder designation are intended to experience 0 to 3 million cumulative equivalent single axle loads (ESALs); intermediate mix types up to 10 million ESALs; and base mix types up to 20 million cumulative ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This designation should perform well in low to medium traffic loading situations.

**'D'** - The 'D' designation corresponds with a Performance Graded (PG) asphalt binder of PG 70-22. Surface asphalt mix types using the 'D' binder designation are intended to experience 3 to 10 million cumulative equivalent single axle loads (ESALs); intermediate mix types between 10 and 20 million ESALs; and base mix types exceeding 20 million cumulative ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This designation should perform well in medium to high traffic loading situations.

**'E'** - The 'E' designation corresponds with a Performance Graded (PG) asphalt binder of PG 76-22 with polymer modification. Surface asphalt mix types using the 'E' binder designation are intended to experience in excess of 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types above 20 million ESALs over a specified design life. In general applications, the 'E' binder designation is not used in a base mix. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. Mixes with this binder designation should perform well in high to extremely high traffic loading situations. The stiffness of mixes using this binder should not be used as a substitute for deficient pavement structure (high deflections under traffic loadings will destroy any pavement structure).

**(S) Stabilized** - designation indicates the use of a PG 64-22 binder with an approved stabilizing additive from the Department's approved list in the Materials Division Manual of Instructions. This designation can be used in extreme traffic loading situations. This

designation does not provide resistance to reflective cracking. This designation should only be combined with ‘A’ mixes.

**(b) Gap Graded and Specialty HMA Binders**

**PG 70-22** – Like the ‘D’ designation for dense graded mixes, this binder is the Performance Graded (PG) 70-22. Surface asphalt mix types using the PG 70-22 binder are intended to experience 3 to 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types between 10 and 20 million ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This binder should perform well in medium to high traffic loading situations and over continuously reinforced concrete pavement.

**PG 76-22** – Like the ‘E’ designation for dense graded mixes, this binder is the Performance Graded (PG) 76-22 with polymer modification. Surface asphalt mix types using the ‘E’ binder are intended to experience in excess of 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types above 20 million ESALs over a specified service life. In general applications, the PG 76-22 asphalt binders are not used in a base mix. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. These designations should perform well in high to extremely high traffic loading situations and over jointed concrete pavement. The stiffness of this mix should not be used as a substitute for deficient pavement structure (high deflections under traffic loadings will destroy any pavement structure).

**PG 70-28** – This binder is a polymer modified Performance Graded (PG) 70-28. The purpose of this binder is to resist thermal cracking and minimize reflective cracking over jointed concrete pavement.

**SEC. 605.04 ASPHALT BINDER AND MIX SELECTION – GENERAL**

**APPLICATIONS**

When making a determination regarding which asphalt mix type to use, the cumulative ESALs must be calculated and the pavement type must be known (new construction, existing flexible pavement or existing rigid pavement). The expected service life of the asphalt layer is necessary to calculate cumulative ESALs for selecting the mix type to use. The service life of the layer is a function of the layer’s position within the pavement’s structure and the asphalt mix as described in Section 605.02. Table 1 provides the expected service life for each layer.

**NOTE:** Preliminary analysis and field experience indicate gap graded mixes generally outperform conventional mixes; therefore, justifying the additional cost for the gap graded mixes. Further investigation will be performed to quantify the actual service life of each mix and calibrate the pavement models.

Layer	Expected Life (yrs)		Comments
	New Const.	Overlay	
Surface	12	12	10 yrs for 2 Lane Roads for dense graded mixes
Intermediate	20	20	
Base	30	30	Generally an 'A' mix is used for most applications

**Table 5 – Expected Service Life by Asphalt Layer**

**(a) Asphalt Binder Selection**

Once the expected service life is selected, then the cumulative equivalent single axle loads (ESALs) must be calculated for selecting the appropriate binder. (Refer to Section 604 of the Manual of Instructions for the procedure in calculating cumulative ESALs.) Tables 2 through 6 summarize the binder selection process based on pavement layer, cumulative ESALs and pavement type. Note: the suggested binder is stiffer for overlay of rigid pavements than flexible pavements for equivalent ESAL levels.

**(b) Asphalt Mix Selection**

During the pavement evaluation and design process, a total asphalt thickness is determined. From this thickness, a series of asphalt lifts are used to construct the pavement structure. For the base layer, one or more lifts may be required. VDOT has one base mix, BM-25.0, for use in construction, reconstruction or major rehabilitation

VDOT has two intermediate and five surface mixes for use in construction, reconstruction or rehabilitation. Tables 2 through 6 summarize the mixes available for various layers based on cumulative ESALs and pavement type.

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	SM-9.0A or SM-9.5A	SM-9.5D or SM-12.5D	SM-9.5D or SM-12.5D
3 to 10 million	SM-9.5D or SM-12.5D	SM-9.5E or SM-12.5E	SM-9.5D or SM-12.5D
> 10 million	SM-9.5E or SM-12.5E	SM-9.5E or SM-12.5E	SM-9.5D or SM-12.5D

**Table 6 – Dense Graded Surface Selection**

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	IM-19.0A	IM-19.0D	IM-19.0D
3 to 10 million	IM-19.0A	IM-19.0E	IM-19.0D
> 10 million	IM-19.0D	IM-19.0E	IM-19.0D

Table 7 – Dense Graded Intermediate Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 to 20 million	BM-25.0A	BM-25.0A	BM-25.0A
> 20 million	BM-25.0D	BM-25.0D	BM-25.0D

Table 8 – Dense Graded Base Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	NR	NR	NR
3 to 10 million	SMA-9.5(70-22) or SMA-12.5(70-22)	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)
> 10 million	SMA-9.5(70-22)* or SMA-12.5(70-22)*	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)

NR – Gap graded mixes are not recommended

\* Consideration to use of a PG 76-22 binder should be given when the Cumulative ESALS are greater than 20 million.

Table 9 – Gap Graded (SMA) Surface Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	NR	NR	NR
3 to 10 million	SMA-9.5(70-22) or SMA-12.5(70-22)	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)
> 10 million	SMA-9.5(70-22)* or SMA-12.5(70-22)*	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)

NR – Gap graded mixes are not recommended

Table 10 – Gap Graded (SMA) Intermediate Layer Selection

**SEC. 605.05 ASPHALT BINDER AND MIX SELECTION – SPECIALIZED****LOCATIONS**

There will be times when a designer needs to select binder and mix types in areas with high truck percentages and slow speeds, excessive grades (>6%) and standing traffic which result in extreme pavement loadings. Some examples of these areas are truck climbing lanes, quarry roads, or truck parking areas. In these situations, the designer should select a binder with high stiffness to resist movement under load. To aide the designer, Table 7 lists the mixes that can be used in the extreme loading situations.

<b>Mix Type</b>	<b>Surface</b>	<b>Intermediate</b>	<b>Base</b>
Truck Climbing Lane and Roads with Excessive Grades (>6%)	SM-9.5E SM-12.5E SM-19.0D SMA-9.5 (76-22) SMA-12.5 (76-22)	IM-19.0D IM-19.0E SMA-19.0 (76-22)	BM-25.0D
Industrial Route, Quarry	SM-9.5D SM-9.5E SM-12.5D SM-12.5E	IM-19.0D IM-19.0E	BM-25.0A BM-25.0D
Truck Parking Area	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D
Intersections with Heavy Truck Percentage	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D
Heavy Urban Traffic with Buses	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D

**Table 11 – Specialized Pavement Locations****SEC. 605.06 APPLICATION RATES**

The normal application rate for a single lift thickness for the various mixes is shown in Table 8. Deviations to the normal application rate should be done in accordance with Section 315.05 (c) of the Road and Bridge Specifications.

<b>Asphalt Concrete Mixes</b>	<b>Nominal Maximum Aggregate Size</b>	<b>Normal Application Rate</b> <sup>Note 1</sup>
<b>Surface Mix</b>		
SM-9.0	3/8 inch (9.5 mm)	1 inch – 110 lb/ yd <sup>2</sup> (25.0 mm – 60 kg/m <sup>2</sup> )
SM-9.5	3/8 inch (9.5 mm)	1.5 inch - 165 lb/yd <sup>2</sup> (40.0 mm – 90 kg/m <sup>2</sup> )
SM-12.5	1/2 inch (12.5 mm)	1.5 inch - 165 lb/yd <sup>2</sup> (40.0 mm – 90 kg/m <sup>2</sup> )
SM-19.0	3/4 inch (19.0 mm)	2 inch – 220 lb/yd <sup>2</sup> (50.0 mm – 125 kg/m <sup>2</sup> )
SMA-9.5	3/8 inch (9.5 mm)	1.5 inch - 165 lb/yd <sup>2</sup> (40.0 mm – 90 kg/m <sup>2</sup> )

Asphalt Concrete Mixes	Nominal Maximum Aggregate Size	Normal Application Rate <sup>Note 1</sup>
<b>Surface Mix</b>		
SMA-12.5	1/2 inch (12.5 mm)	1.5 inch - 165 lb/yd <sup>2</sup> (40.0 mm – 90 kg/m <sup>2</sup> )
<b>Intermediate Mix</b>		
SMA 19.0 (intermediate)	1/2 to 1 inch (12.5 to 19.0mm) <sup>Note 2</sup>	2 inch – 220 lb/yd <sup>2</sup> (50.0 mm – 125 kg/m <sup>2</sup> )
IM-19.0	3/4 inch (19.0 mm)	2 inch – 220 lb/yd <sup>2</sup> (50.0 mm – 125 kg/m <sup>2</sup> )
<b>Base Mix</b>		
BM-25.0	1 inch (25.0 mm)	3.0 inch <sup>Note 3</sup> (75.0 mm)
<b>Open Graded Drainage Layer</b>		
OGDL	--	2.0 inch (50 mm)
<b>Thin Hot Mix Asphalt Concrete</b>		
THMACO	--	3/4 inch (19.0 mm)

Note 1 Application rate is based upon 110 pounds per square yard per inch (2.35 kilograms per square meter per millimeter) of thickness.

Note 2 SMA Intermediate design criterion allows the mixture to meet the definition of either nominal maximum aggregate size.

Note 3 Application rate for BM Type mixes should be determined from the actual specific gravity of the mixture as called for by the Materials Division or by region as indicated in Table 9.

**Table 12 – VDOT Mix Comparison Table**

### **SEC. 605.07 TYPICAL ASPHALT BASE MIX APPLICATION RATES**

Table 9 should be used to determine the approximate quantity of base asphalt for construction and maintenance program projects. This table contains the average weight for the base mix based on the aggregate present in the District.

<b>VIRGINIA DEPARTMENT OF TRANSPORTATION WEIGHT OF BASE ASPHALT MIXES FOR APPROXIMATE QUANTITY CALCULATIONS</b>			
DISTRICT	AREAS	Mass kg/m <sup>2</sup> /mm	Lbs/S.Y./In
Bristol	Abingdon-Marion-Wytheville-Galax	2.46	115
	Bluefield-Big Stone Gap-Woodway-Bristol	2.39	112
Salem	Buchanan-Roanoke-Salem-Radford-Martinsville	2.43	114

**VIRGINIA DEPARTMENT OF TRANSPORTATION  
WEIGHT OF BASE ASPHALT MIXES FOR APPROXIMATE  
QUANTITY CALCULATIONS**

DISTRICT	AREAS	Mass kg/m <sup>2</sup> /mm	Lbs/S.Y./In
Lynchburg	Lynchburg	2.41	113
	Danville	2.35	110
	South Boston	2.37	111
Richmond		2.35	110
Hampton Roads		2.35	110
Fredericksburg		2.35	110
Culpeper	Charlottesville	2.52	118
	Culpeper - Flint Hill	2.41	113
Staunton		2.39	112
NOVA	Arlington - Fairfax	2.61	122

**Table 13 – Application Rates for Asphalt Base Mix**



## **SECTION 606 – PAVEMENT TYPE SELECTION PROCEDURES**

### **SEC. 606.01 INTRODUCTION**

This document outlines VDOT's Pavement Type Selection Procedures (PTSP) used in selecting the most functional and economical pavement type. These procedures are the results of the cooperation among various groups/divisions of VDOT and both asphalt and concrete industries. These PTSP are to be used with conventional Design Bid Build, Design Build, and Alternate Bidding contracts.

The procedures are aimed to provide the following:

1. Consistency
2. Conciseness
3. Transparency
4. Enhanced competition
5. Identical selection of pavement type by all qualified users upon following these procedures

### **SEC. 606.02 PAVEMENT TYPE SELECTION**

The PTSP are a set of steps that lead to the determination of alternate structures using a variety of materials, pavement design, construction methodologies, and Life Cycle Cost Analysis (LCCA). Therefore, it is possible that more than one type of pavement (typically, asphalt and concrete) could be designed which is capable of accommodating the design traffic under the same environmental condition. However, the differing pavement types will have different cost and maintenance components as well as differing constructability issues. The pavement designer needs to select the type that best satisfies the interest of the Department and the traveling public by thoroughly assessing all the pertinent factors. Such process is called pavement type selection.

### **SEC. 606.03 PAVEMENT TYPES**

#### **Pavement Types**

Pavement types are broadly categorized into the following:

- Flexible pavement
  - Asphalt pavement
- Rigid pavements
  - Jointed Plain Concrete Pavement (JPCP)
  - Jointed Reinforced Concrete Pavement (JRCP)
  - Continuously Reinforced Concrete Pavement (CRCP)
- Composite pavements (asphalt over concrete surface is typical in VA)

## **SEC. 606.04 PAVEMENT DESIGN**

Pavement design is the process of selecting a practical and economical combination of materials of known strength and adequate thicknesses to support anticipated traffic under the prevailing environmental conditions. VDOT uses two different methods for pavement design. The 1993 AASHTO Guide for Design of Pavement Structures is used for interstate and primary roads. A separate indigenous design method described in VDOT's "Pavement Design Guide for Subdivision and Secondary Roads in Virginia" is followed for secondary roads. High volume secondary roads, as defined in the referenced secondary pavement design document, are also recommended to be designed following the 1993 AASHTO method. In order to ensure consistency, the pavement type selection process shall be applied only for pavements that are designed following the AASHTO method (i.e., interstate, primary and high volume secondary roads). The 1993 AASHTO design process is outlined in Chapter VI of Materials Division's Manual of Instructions.

## **SEC. 606.05 PAVEMENT TYPE SELECTION PROCEDURES (PTSP)**

Typically, the following factors influence the selection of pavement types:

- Cost (both initial and future maintenance/rehabilitation)
- Geometry of the pavement to be built (if applicable)
- Geometry of the adjacent pavement (if applicable)
- Existing appurtenant features (median barriers, drainage structures, curb & gutters, lateral & overhead clearances, structures limiting the new or rehabilitated pavement structure)
- Maintenance of traffic
- Availability of local materials
- Maintaining or changing grade profile
- Corridor continuity
- Local experience

The pavement type selection process is not an exact science as it involves not only engineering analysis but also subjective and complex consideration to project constraints which may or may not be agreed upon by all concerned. This is very important since it significantly impacts the Department's budgetary and resource need. For typical projects, PTSP initiate at the project scope which determines if the project will be a candidate for considering multiple pavement types. The process then involves the following components: design of alternatives, performing life cycle cost analysis, selection of pavement type, development of typical pavement section, signing/sealing of the selected pavement section, forwarding the typical section to the project manager and project advertisement. In general, the following four steps should be followed when selecting a pavement type for typical projects (alternate bid projects follow a slightly different process which is explained in Alternate Bidding Section of this document):

Step 1: Decide if multiple pavement types need to be considered

Step 2: Design different types of pavement

Step 3: Perform Life Cycle Cost Analysis (LCCA) on competing pavement types

Step 4: Select the pavement type

These steps are discussed in detail in the following sections.

### **Step 1: Decide if multiple pavement types need to be considered**

Two major categories are encountered in this step, namely: new alignment/reconstruction and rehabilitation projects. New alignment or reconstruction projects are generated from the six year plan, while the rehabilitation projects are initiated from the Maintenance Division's pavement management process. While new alignment/reconstruction projects are prevailing examples, multiple pavement types could be considered for major rehabilitation projects as well. A general guideline for the criteria when multiple pavement types should be considered is provided below.

#### New Construction

New construction type projects could be sub-divided into the following two categories:

##### 1. New Alignment:

Typically, brand new alignment projects are most suitable for considering multiple types of pavements. However, length and structure of the pavement are to be considered in deciding whether multiple pavement types provide realistic solutions. For example, pavement type for a new section that is too short could be simply decided by the pavement it is joining to. At the same time, multiple pavement types may not be realistic if the pavement structure is too thin. If the length of the project is at least 4 centerline miles or at least 16 lane miles and the design Structural Number (SN) for AC pavement is at least 5 or design concrete pavement thickness is at least 8 inches then multiple pavement types should be considered for new alignment projects. This means if the designer starts with asphalt section and the section meets the above length criteria and the design SN is at least 5 then an equivalent concrete section needs will be considered and the steps described in this document will be followed to select the final pavement type. At the same time, if the designer starts with concrete section and the section meets the above length criteria and the design PCC thickness is at least 8 inches then an equivalent asphalt section will be considered. The steps described in this document will then be followed to select the final pavement type.

##### 2. Reconstruction:

Reconstruction projects could involve either the same footprint or widening of an existing road and the following criteria are applied for selecting PTSP candidates.

- a. For reconstruction along the same footprint projects, if the length of the project is at least 4 directional miles or at least 8 lane miles and the design Structural Number (SN) for AC pavement is at least 5 or design concrete pavement thickness is at least 8 inches then multiple pavement types should be considered. The directional mile is used since reconstruction may often involve only one direction of a divided roadway.

- b. For widening projects, if the length of the section is at least 4 miles and the design SN of the existing pavement (if AC) is at least 5 or the thickness of the existing pavement (if PCC) is at least 8 inches, multiple pavement types should be considered.

### Major Rehabilitation

Certain types of major rehab projects may qualify for considering multiple pavement types. At a minimum, the rehabilitation solution should provide a design life of 20 years. In addition, if the length is at least 4 directional miles or at least 8 lane miles and the new design SN (for AC pavement) is at least 5 or the new design pavement thickness (for PCC pavement) is at least 8 inches, multiple pavement types should be considered.

The criteria and process described above are shown in Figure 1 with a detailed flowchart.

Situations where the above conditions are not met, pavement type is usually governed by adjacent or existing pavement or special needs. As a general guideline, following are some typical examples (not all inclusive) where multiple pavement types need not be considered:

1. Turning lane
2. Functional maintenance projects (for example, single lift Asphalt resurfacing projects)
3. Pavement preservation projects (for example, surface treatment, slurry seals etc.)

### **Step 2: Design different types of pavements**

Once it is decided to consider multiple pavement types for the project and the possible alternate pavement types are identified, the appropriate pavements shall be designed following Chapter VI of Materials Division's Manual of Instruction (MOI) which utilizes the 1993 AASHTO method of pavement design. As noted earlier, high volume secondary roads are recommended to be designed following the 1993 AASHTO method.

### **Step 3: Perform Life Cycle Cost Analysis (LCCA)**

After designing the possible alternate pavement sections, Life Cycle Cost Analysis (LCCA) is to be performed to assess the economic worth of the alternate pavement sections. This consists of the initial cost estimate of the paving materials and the future maintenance activities necessary to maintain the road at an acceptable serviceability level to the traveling public. These activities include maintaining the pavement quality, namely smoothness and safety in terms of non-skidding, and the structural capacity, namely the elimination of cracks, faulting, potholes, and rutting. The present worth (PW) approach is generally used to represent the translation of specified amounts of costs or benefits occurring in different time periods into a single amount at present instant. However, Equivalent Uniform Annual Cost (EUAC) approach is used for certain major rehab projects where the design life between the competing options are not the same.

In PW approach, LCCA converts the initial and all expected maintenance/rehabilitation costs of the differing pavement types into present worth values. In EUAC approach, the calculated PW is evenly distributed over the analysis period. For details on VDOT's

LCCA approach, please see the document titled “Guidelines for Life Cycle Cost Analysis” or Section 607 of Materials Division’s Manual of Instruction (Chapter VI).

#### **Step 4: Select the final pavement type**

If the present worth (or EUAC for certain major rehab projects) values in the LCCA for the competing pavement type solutions differ more than 10%, the pavement type with the lowest present worth (or EUAC for certain major rehab projects) shall be recommended for final selection. When the net present worth (or EUAC for certain major rehab projects) for competing types of pavements is within 10%, other factors are examined as outlined in VDOT’s LCCA process (for non alternate bid projects) or the project is selected for alternate bidding (see the section on Alternate Bidding below for alternate bidding project selection criteria). If the project is not an alternate bid candidate, other factors that are not considered in the LCCA computation should be considered in conjunction with LCCA results. These factors along with the LCCA results are considered to make the final decision. These factors could be, but are not limited to:

- Initial project constructability
- Constructability of future improvements
- Volume of traffic
- Maintenance of traffic
- Climate
- Recycling
- Adjacent existing pavement (if applicable)
- Traffic safety
- Incorporation of experimental features
- Participating local government preference

If any particular type of pavement is disregarded due to special circumstances despite the favorable LCCA result, appropriate justification shall be documented and approved by the State Materials Engineer or his designee. For projects that are selected for alternate bidding process, the final pavement type will be selected based on the outcome of the alternate bidding process.

#### **SEC. 606.06 ALTERNATE BIDDING**

Alternate bidding is the process where bids are solicited on two different pavement types for the same project. The final pavement type selection is based on the actual bid price of the project (not the pavement components only). Such practice, if applied to the right project, is expected to enhance competition within the contracting industry and potentially lead to lower costs for VDOT.

New construction and complete reconstruction projects meeting the criteria as described in Step 1 (and also outlined in Figure 1) are suitable candidates for the alternate bidding process. VDOT will perform LCCA on these projects based on the best estimates of the unit prices. If the difference between the PW for competing pavement types are within

10%, VDOT will pursue alternate bidding. Each alternate will be included in the bid package for solicitation. The final selection of the pavement type will be based on the least bid amount for the project. For Design Build projects, the final selection of the pavement type will follow the standard award process for Design Build projects.

It should be noted that alternate bidding may be considered for projects not meeting the above criteria but is deemed to provide opportunities for competition. Such decision should be made on case by case basis and approved by the State Materials Engineer or his designee.

#### **SEC. 606.07 HOW TO USE THE PROCEDURES**

Pavement type selection procedures (PTSP) start at the scoping of any project. The scoping determines whether multiple pavement types are practical and the project is a candidate for PTSP. The procedures should involve the following:

1. Start with the project scope and use the decision flow chart in Figure 1 to select the proper category
2. Follow the applicable procedures

If a project is not a candidate for Pavement Type Selection Procedures (PTSP), the standard VDOT design process will be followed. This will involve detailed design of the selected pavement type, signing/sealing by the respective design engineer and forwarding the design to the respective project manager. On the other hand, if the project is a PTSP candidate, multiple pavement types will be considered and designed. Life Cycle Cost Analysis (LCCA) will be performed following VDOT's LCCA process to assist in the determination of the final pavement type. The selected pavement design is signed and sealed by the respective design engineer and is ultimately forwarded to the project manager. If a project is selected for alternate bidding, the design engineer will sign and seal both pavement types and forward these two pavement designs to the project manager. Bids will be solicited on both these sections and the selection of the pavement type will be determined based on the least bid price of the project or following the standard award process for Design Build projects.

The pavement type selection process shall be performed under the purview of the respective District Materials Engineer or his designee. If the project is a candidate for Central Office Materials (CO) review (interstate and primary routes for brand new alignments), the project details and pavement design recommendations shall be sent to CO Pavement Design and Evaluation section for review after an LCCA is performed. Interstate and Primary route candidates for rehabilitation may be sent to CO for review at the District Materials Engineer's discretion. The State Materials Engineer or his designee will review the project upon consultation with the district and issue a written letter of concurrence and/or noting any concern or issues. The District Materials Engineer or his designee will then finalize the pavement type, sign and seal the pavement design and forward it to the respective project manager for incorporation into the project plans and contract documents. The State Materials Engineer will have the final decision authority over any unresolved technical matters related to the project pavement type selection or pavement design. For projects where the alternate bid process is used, both alternates with the applicable plan sheets and other pertinent contract documents shall be included

in the bid package. The final selection of the pavement type will be made after receiving bids. A flowchart summary of the process is shown in Figure 1. Any deviation from the policies and procedures described herein must be documented by the project design staff and approved by the State Materials Engineer or his designee.

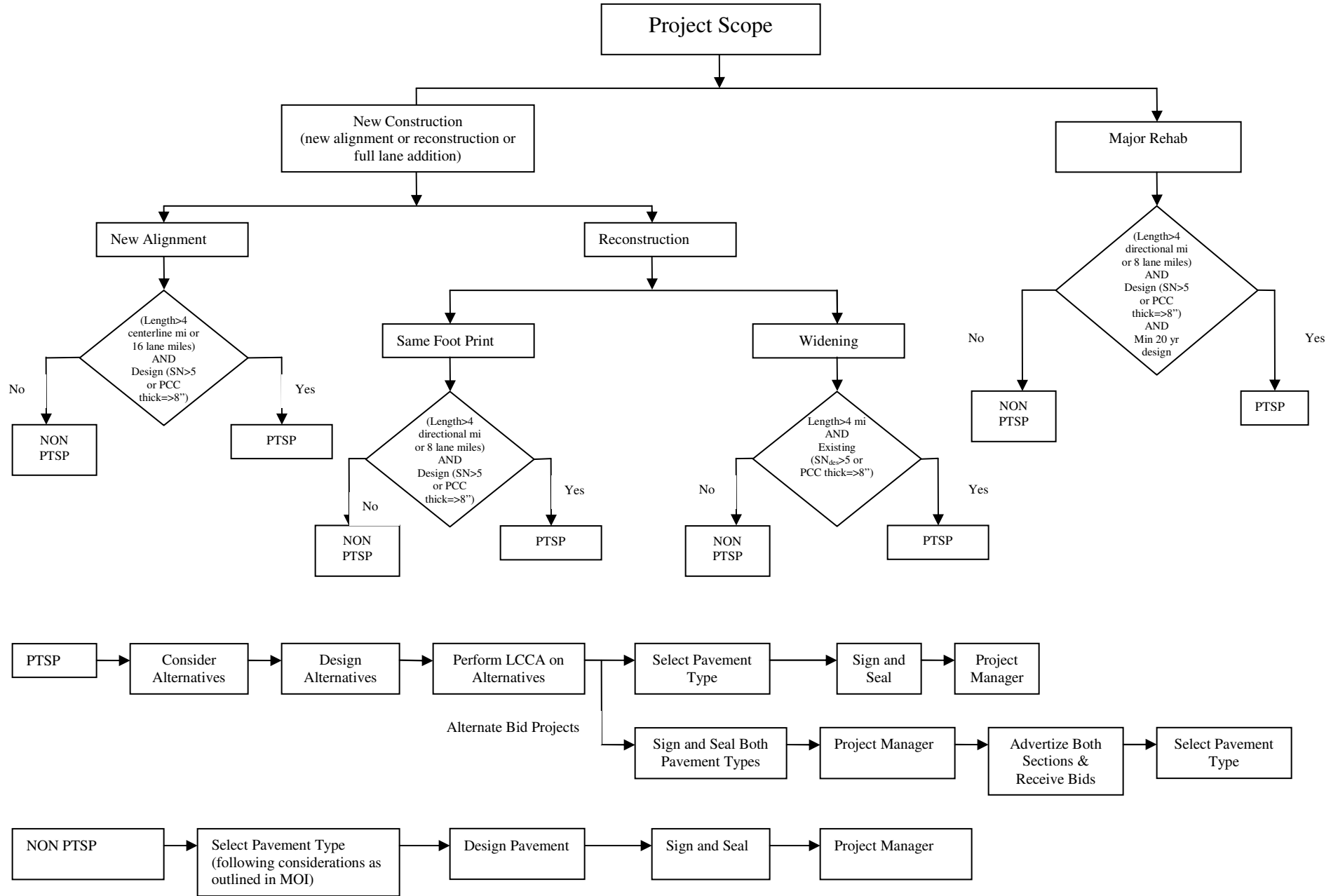


Figure 1: Pavement Type Selection Decision Work Flow



## **SECTION 607 – LIFE CYCLE COST ANALYSIS**

### **SEC. 607.01 EXECUTIVE SUMMARY**

With increasing customer expectations and limited funding, VDOT must ensure that the most cost-effective, smooth, and long-lasting pavements are constructed on Virginia's highways. With the volume of traffic using Virginia's highways, the public will no longer tolerate excessive work-zone disruptions because of emergency or unplanned maintenance on a roadway. Additionally, VDOT cannot afford to rehabilitate these pavements prematurely. Both the public and VDOT want VDOT to "Get In, Get Out, and Stay Out." To fulfill this expectation, VDOT is designing pavements using new approaches and enhanced state-of-the-art materials.

VDOT like many other agencies utilizes life cycle cost analysis (LCCA) procedure into the process of selecting pavement type. This analysis incorporates proven national methodologies customized to Virginia's unique circumstances. VDOT looks beyond initial construction costs by considering the future maintenance and rehabilitation needs associated with a particular type of pavement. This approach, then, improves the decision-making process by enabling the selection of the most cost-effective type of pavement based on an estimation of *costs incurred* throughout a suitable analysis period, or "life cycle." For the LCCA procedure, a 50-year analysis period is considered sufficiently long to capture the maintenance and rehabilitation costs that span at least one full series of treatment activities with the exception of major rehab type projects where the analysis period is taken as the design life for the competing pavement options.

The procedure herein was derived largely from the Federal Highway Administration Technical Bulletin, *Life Cycle Cost Analysis in Pavement Design*, discussion with various stakeholders and both asphalt and concrete industries. Geared toward state highway agency personnel responsible for designing highway pavements, the FHWA bulletin provides technical guidance and recommendations on "good practice" in conducting LCCA in pavement design. It was authored by representatives of various state transportation departments, the Federal Highway Administration (FHWA), the National Asphalt Pavement Association, and the American Concrete Pavement Association. Additionally, VDOT's LCCA Guidelines draw upon the experience and expertise of its own workforce, particularly in areas related to pavement performance prediction and maintenance effectiveness as well as practices by other agencies. Where records are available, historic performance data were used to support planned maintenance/rehabilitation intervals for certain activities.

LCCA will enhance VDOT's ability to make sound engineering and cost-effective economic decisions pertaining to the construction/reconstruction and major rehabilitations of Virginia's major highways. However, it is important to remember that the LCCA process is based on the premise that the pavements are properly designed and will be reasonably maintained, that the quality of the construction and materials is consistently good, and that the pavement is not subject to adverse or unforeseen site conditions. Performance of the different pavement types and extent of specific rehabilitation treatment had been established based on available performance data, local practice and engineering judgments. Actual performance and the exact extent of the

specific rehabilitation treatment of a particular project could be different. However, established parameters reflect the best possible realistic and practical assumptions that are needed to be made to perform LCCA computations.

## **SEC. 607.02 INTRODUCTION**

A major factor in selecting the type of pavement for use on new construction and major rehabilitation projects is cost. In many cases, the initial construction cost is the main consideration. Although a particular pavement type may have a low initial cost, the future maintenance and rehabilitation costs may be exorbitant and, therefore, must be considered in a fair and objective decision-making process. In order to account for the initial and future costs associated with the construction and maintenance of roadway infrastructure, a life cycle cost analysis (LCCA) should be performed. LCCA may not be necessary on all projects largely because of the nature and location of a particular project. LCCA is necessary for projects where multiple pavement types are feasible and considered. Materials Division's "Pavement Type Selection Procedures" document (section 606 of Chapter VI of MOI) outlines the situations where multiple pavement types should be considered and hence LCCA needs to be performed in order to select the most cost effective option.

### **Purpose**

The purpose of this document is to provide technical guidance to VDOT engineers involved in selecting a pavement type for major construction and rehabilitation projects that provides the best cost effective solution. Separate tables have been generated and presented herein outlining the assumed performance and rehabilitation year and treatment for separate pavement type.

### **What is LCCA?**

LCCA is an economic method to compare alternatives that satisfy a need in order to determine the lowest cost alternative. According to Chapter 3 of the *AASHTO Guide for Design of Pavement Structures*, life cycle costs "refer to all costs which are involved in the provision of a pavement during its complete life cycle." These costs borne by the agency include the costs associated with initial construction and future maintenance and rehabilitation. Additionally, costs are borne by the traveling public and overall economy in terms of user delay. The life cycle starts when the project is initiated and opened to traffic and ends when the initial pavement structure is no longer serviceable and reconstruction is necessary.

### **History of LCCA in VDOT**

VDOT has used LCCA to evaluate and select pavement types on new Interstate and Primary Route projects for many years. Past LCCAs for pavements considered a 24-foot surface width and dealt with the cost for a lane mile. A 30-year analysis period was used, and only continuously reinforced concrete, jointed concrete, and flexible pavements were considered. In 2002, VDOT's LCCA was revised. One of the major changes was incorporation of 50 year analysis period and inclusion of the entire project cost as

opposed to lane mile cost. The current revision (in 2011) reflects the updated performance of some materials and treatment, elimination of salvage value and inclusion of select major rehabilitation projects for LCCA process.

## **SEC. 607.03 ECONOMIC ANALYSIS COMPONENTS**

### **Analysis Period**

To maintain consistency with the FHWA Technical Bulletin, *Life Cycle Cost Analysis in Pavement Design*, LCCA periods should be sufficiently long to reflect long-term differences associated with reasonable maintenance strategies. The analysis period should generally be longer than the pavement design period. As a rule of thumb, the analysis period should be long enough to incorporate at least one complete cycle of rehabilitation activity. The FHWA's September 1996 Final LCCA Policy Statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects and rehabilitation, restoration, and resurfacing projects. For VDOT's LCCA procedure, a 50-year analysis period was selected for new construction and reconstruction type projects. This period is sufficiently long to reflect the service lives of several rehabilitation activities. For major rehab type projects where multiple pavement types are considered and LCCA is required, the analysis period is taken to be the design life of the rehab design.

### **Discount Rate**

In order to account for the cost related to future activities, the time value of money must be considered. In LCCA, the discount rate is used. The *discount rate* is defined as the difference between interest and inflation rates. Historically, this value has ranged from 2% to 5%; for LCCA purposes, a value of 4% will be used. This value is consistent with the values recommended in the FHWA Interim Technical Bulletin and practices by many other state agencies. The discount rate accounts not only for the increased cost associated with performing an activity in the future but also for the economic benefit the agency would receive if those funds were instead invested in an interest-bearing account.

### **Evaluation Methods**

Numerous economic analysis methods can be used to evaluate pavement alternatives. The two most common are the present worth (PW) method and the equivalent uniform annual cost (EUAC) method.

The EUAC method describes the average cost an agency will pay per year over the analysis period. All costs including initial construction and future maintenance are distributed evenly. Although this dollar value may not seem realistic in years when little pavement action is required, it can be used to evaluate and compare alternatives.

The PW method reports initial and future pavement costs as a lump sum amount in today's dollar value. For activities that occur in the initial year of the analysis period, the PW cost is the same as the actual cost, i.e., no adjustment for inflation and interest. For future maintenance and rehabilitation activities, the PW cost is less than the actual cost (based on

today's unit prices) since total costs are discounted. Please note that for two identical actions that occur 30 years apart, the later action will cost much less. This is because of the number of years that are discounted. The PW method is the more widely used approach for pavement LCCA. It gives an indication of how much a pavement alternative will cost over the analysis period and can be used to clearly compare alternatives for lowest cost. The formula to compute both PW and EUAC are provided below.

$$PW = \text{Initial cost} + \sum_{k=1}^n \text{RehabCost}_k * \left[ \frac{1}{(1+i)^n} \right]$$

Where:            i = discount rate  
                       k = year of activity  
                       n = analysis period

$$EUAC = PW * \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]$$

Where:            i = discount rate  
                       n = analysis period

### **Sensitivity Analysis**

As with any analysis, it is important to understand what variables make the largest difference in the final results. For pavement design, the pavement subgrade strength and traffic loading have the largest impact on the design outcome. For LCCA, multiple variables can affect the final PW or EUAC for a pavement alternative. For example, the unit cost of a material alone can be significant enough to cause a particular alternative go from the lowest PW to the highest. Therefore, the engineer must ensure that the unit costs used are reasonable; likewise, it is important to understand how sensitive the cost of an alternative is to the input assumptions. This is accomplished by performing a limited sensitivity analysis whereby various combinations of inputs are selected to qualify their effect on the analysis results. Other factors that can influence the LCCA results are analysis period, and timing of activities.

### **SEC. 607.04 COST FACTORS**

Numerous costs are included in LCCA for pavements, ranging from initial costs associated with new construction to future maintenance costs associated with patching, sealing, and other activities.

### **Initial Costs**

To conduct an LCCA for comparing pavement alternatives, the initial cost is a major percentage of the PW or EUAC over the analysis period. The initial cost is determined at Year 0 of the analysis period.

Although numerous activities are performed during the construction, reconstruction, or major rehabilitation of a pavement, only those activities that are specific to a pavement alternative should be included in the initial costs. By focusing on those activities, the engineer can concentrate on estimating the quantities and costs related to those activities. Actions dependent on pavement type include, but are not limited to the following:

- milling
- pavement removal
- asphalt concrete paving
- portland cement concrete paving
- fracturing portland cement concrete slabs

### **Rehabilitation Costs**

For all pavement options, the initial pavement life is designed to support traffic for 30 years. At around the end of the 30-year period, the pavement must be rehabilitated. For flexible pavements, this rehabilitation generally includes removing AC surface and intermediate materials and replacing with new AC material. For rigid pavements, concrete pavement restoration (CPR) is generally conducted and an AC overlay may be placed. However, wherever feasible, concrete overlays could also be considered on both asphalt and concrete pavements. Rehabilitation activities may include but are not limited to the following:

- milling
- AC paving
- PCC and AC patching
- joint cleaning.

### **Structural/Functional Improvement Costs**

Structural/functional improvement activities are performed during the life of a pavement in order to maintain a smooth, safe, durable pavement surface. Structural/functional improvements are designed to last 10 years (higher life for SMA mixes). Typical improvement activities include the following:

- milling
- AC and PCC patching
- AC paving
- PCC grinding
- joint cleaning and sealing

### **Maintenance Costs**

All pavement types require preventive and corrective maintenance during their service life. The timing and extent of these activities vary from year to year. Routine reactive

type maintenance cost data are normally not available except on a very general, area wide type cost per lane mile. Fortunately, routine reactive type maintenance costs are generally not very high due to the relatively high performance levels maintained on major highway facilities. Further, state highway agencies that do report routine reactive maintenance costs note little difference between most alternative pavement strategies. When discounted to the present, small reactive maintenance cost differences have negligible effect on PW and can generally be ignored. Therefore, they are not included in this LCCA procedure.

### **Salvage Value**

At the end of the LCCA period, the pavement structure may be defined as having some remaining value to the managing agency, known as the salvage value. Different pavement types attain different condition at the end of the analysis period. If the condition of the pavement at the end of the analysis period is such that a complete removal and replacement is warranted, then the salvage value would have been the cost of any residual materials obtained from the pavement system (materialized by the agency). However, in most situations and depending on the timing and extent of the last maintenance treatment, the pavement either continues to remain in service or some kind of rehabilitation treatment is performed on the existing pavement (which may involve partial removal of the pavement materials or reclamation type treatment combined with overlays). So, pavements typically offer some sort of remaining life at the end of analysis period. In such cases, the residual value of the materials are not realized. Therefore, the remaining life essentially represents the salvage value of the pavement for practical purpose. Estimating a dollar figure for this component could be complex. Fortunately, the dollar figures for the 'salvage value' for the competing pavement types when discounted 50 years to PW are not expected to be significantly different. For simplicity, VDOT disregards the salvage value for the competing pavement types in its LCCA process.

## **SEC. 607.05 OVERVIEW OF LCCA PAVEMENT OPTIONS**

In order to conduct a LCCA, different pavement options must be identified and compared for a project. The number and type of viable pavement options depend on the project's characteristics. After an examination of the pavement structures (flexible, rigid, and composite), six pavement options were created. The following table identifies these pavement options:

<b>Construction/Major Rehabilitation Pavement Options</b>
Asphalt Concrete Construction/Reconstruction
Jointed Plain Concrete Construction/Reconstruction with Tied PCC Shoulders
Jointed Plain Concrete Construction/Reconstruction with Wide Lane and AC Shoulders
Continuously Reinforced Concrete Pavement Construction/Reconstruction with Tied PCC Shoulders
Continuously Reinforced Concrete Pavement Construction/Reconstruction with Wide Lane and AC Shoulders
Major Rehabilitation

The pavement options, criteria and suppositions in the table were made to accommodate the consistent application of LCCA across the state. Without these guidelines, an infinite number of pavement options could be developed. For some pavement options, specific criteria and suppositions were made. The general criteria and suppositions made are summarized below. It should be noted that the actual rehabilitation treatment on a particular pavement may be different from these assumptions. The assumptions made in this LCCA document reflect the prevailing VDOT practice and does not necessarily put a binding requirement on the pavement engineers while rehabilitating pavements. For example, unbonded or bonded PCC overlay could be considered to rehab a PCC section if such treatment provides the best solution to the specific circumstance even though it is not programmed in the LCCA process for PCC pavements.

The general criteria and suppositions made are:

- No reconstruction is planned during the analysis period beyond the original rehabilitation/reconstruction.
- Flexible pavements remain flexible throughout the analysis period, i.e., no white-topping.
- Rigid pavements are overlaid with AC during the analysis period. No unbonded or bonded concrete overlays are programmed.
- Subsurface drainage systems are independent of pavement type. If a site needs drainage, then all options call for drainage. Therefore, this cost is treated as fixed regardless of pavement type.
- Full-depth shoulders are designed to carry potential future traffic.
- The timing of functional improvements and major rehabilitation is fixed.
- The activities associated with new construction, reconstruction, major rehabilitation, and functional/structural improvements are a function of the project. The activities included in LCCA must be determined by the engineer and supported by documentation.

Reconstruction is defined as the treatment that involves removal (partial or full depth) and/or manipulation of unbound materials for asphalt pavement. Removal and replacement of the concrete pavement (with or without manipulation of unbound materials) are considered reconstruction. Unbonded concrete overlays are considered reconstruction. Bonded concrete pavement is designed to improve structural capacity of the existing pavement and is not considered as reconstruction.

#### **SEC. 607.06 ASPHALT PAVEMENT CONSTRUCTION/RECONSTRUCTION**

For most projects, asphalt pavement construction or reconstruction is a viable option. Asphalt pavement can be constructed on a new alignment or an existing alignment. For existing alignments, the in-situ pavement is removed completely. Asphalt pavement could be utilized to rehabilitate existing PCC pavement through fracturing the PCC pavement

and overlaying with AC layers. Fracturing techniques includes break and seat, crack and seat, and rubblization. The type of fracturing performed is based on the existing rigid pavement type, e.g., jointed plain, jointed reinforced, or continuously reinforced concrete. Once the pavement has been fractured and overlaid, it is considered a flexible pavement structure. Such an option is considered to behave like a new asphalt structure and follow the same life cycle as new AC pavement.

Beginning early 2000, VDOT starts utilizing a premium asphalt mix known as Stone Matrix Asphalt or SMA. This mix provides better performance compared to conventional asphalt mixes. In order to differentiate between the performance of SMA and conventional mixes, two separate performance tables had been generated and presented in this section. The designer needs to use appropriate performance table based on the asphalt mixes to be used in the pavement section.

#### Performance for Dense Graded Mixes

As with all pavement options, several criteria were established and assumptions made:

1. The initial pavement design life is 30 years. Because of functional mill and replace at Year 12 and 22, major rehabilitation is not scheduled until Year 32.
2. For the structural rehabilitation at Year 32, the pavement surface life is 12 years.
3. Functional mill and replace is a fixed activity at Years 12, 22, and 44 in order to provide 10 additional years of life to the pavement surface and structure. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
4. For structural adequacy, the pavement overlay design life at Year 32 is 20 years. Pavement activities and required structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers) at the time of rehab.
5. Patching of AC pavements is based on area of pavement surface.
6. Preventive maintenance activities considered in the analysis include surface treatments (e.g., BSTs, thin overlays, slurries, microsurfacing), crack sealing, and patching. Preventative maintenance is only specified in the analysis for the shoulders if a functional or structural improvement is performed on the mainline pavement. No preventative maintenance is programmed for the mainline pavement as part of the LCCA.



**Pavement Activities Table**

<b>Year 0 – New Construction/Reconstruction</b>	<b>Year 12 – Functional Mill and Replace</b>
Mainline* <ul style="list-style-type: none"> <li>AC Surface Material</li> <li>AC Intermediate Material</li> <li>AC Base Material</li> <li>Stabilized Drainage Layer</li> <li>CTA or DGA Subbase</li> </ul> Shoulders* <ul style="list-style-type: none"> <li>AC Surface Material</li> <li>AC Intermediate Material</li> <li>AC Base Material</li> <li>Stabilized Drainage Layer</li> <li>CTA or DGA Subbase</li> </ul>	Mainline <ul style="list-style-type: none"> <li>Pre-overlay repair - Patch – 1% (up to the top of base layer)</li> <li>Mill – Surface Layer</li> <li>Replace with AC Wearing Course – one layer</li> </ul> Shoulders <ul style="list-style-type: none"> <li>Surface Treatment</li> </ul>
*As appropriate	
<b>Year 22 – Functional Mill and Replace</b>	<b>Year 32 – Major Rehabilitation</b>
Mainline <ul style="list-style-type: none"> <li>Pre-overlay Repair - Patch – 1% (up to the top of base layer)</li> <li>Mill – Surface layer</li> <li>Replace with AC Surface Materials – one layer</li> </ul> Shoulders <ul style="list-style-type: none"> <li>Surface Treatment</li> </ul>	Mainline <ul style="list-style-type: none"> <li>Pre-overlay Repair - Patch – 5% (full depth)</li> <li>Deep Mill (All Surface and Intermediate Layers)</li> <li>Replace with <ul style="list-style-type: none"> <li>AC Base Material</li> <li>AC Intermediate Material</li> <li>AC Wearing Course</li> </ul> </li> </ul> Shoulders <ul style="list-style-type: none"> <li>Overlay with AC Wearing Course</li> </ul>
<b>Year 44 – Functional Mill and Replace</b>	<b>Year 50 – Salvage Value</b>
Mainline <ul style="list-style-type: none"> <li>Pre-overlay repair - Patch – 1% (up to the top of base layer)</li> <li>Mill - Surface layer</li> <li>Replace with AC Wearing Course - one layer</li> </ul> Shoulders <ul style="list-style-type: none"> <li>Surface Treatment</li> </ul>	None

Performance for SMA surface

The designer will consider this section if the pavement is to be built using SMA mixes. As with all pavement options, several criteria were established and assumptions made. It is assumed that the pavement system receives appropriate SMA mixes during all maintenance treatments.

1. The initial pavement design life is 30 years. The pavement system will undergo a functional mill and replace at Year 15 and major rehabilitation is scheduled at Year 28.
2. For the structural rehabilitation at Year 28, the pavement surface life is 15 years (assuming SMA mixes to be used).
3. Functional mill and replace is a fixed activity at Years 15 and 43 in order to provide 13 additional years of life to the pavement surface and structure.
4. For structural adequacy, the pavement overlay design life at Year 28 is 20 years. Pavement activities and required structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers) at the time of the rehab.
5. Patching of AC pavements is based on area of pavement surface.
6. Preventive maintenance activities considered in the analysis include surface treatments (e.g., BSTs, thin overlays, slurries, microsurfacing), crack sealing, and patching. Preventative maintenance is only specified in the analysis for the shoulders if a functional or structural improvement is performed on the mainline pavement. No preventative maintenance is programmed for the mainline pavement as part of the LCCA.

**Pavement Activities Table**

<b>Year 0 – New Construction/Reconstruction</b>	<b>Year 15 – Functional Mill and Replace</b>
<b>Mainline*</b> AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer CTA or DGA Subbase  <b>Shoulders*</b> AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer CTA or DGA Subbase	<b>Mainline</b> Pre-overlay repair - Patch – 1% (up to the top of base layer) Mill - Surface layer Replace with AC Wearing Course - one layer  <b>Shoulders</b> Surface Treatment

\*As appropriate

<b>Year 28 – Major Rehabilitation</b>	<b>Year 43 – Functional mill and replace</b>
Mainline Pre-overlay Repair - Patch – 5% (full depth) Deep Mill (All Surface and Intermediate Layers) Replace with AC Base Material AC Intermediate Material AC Wearing Course  Shoulders Overlay with AC Wearing Course	Mainline Pre-overlay repair - Patch – 1% (up to the top of base layer) Mill - Surface layer Replace with AC Wearing Course - one layer  Shoulders Surface Treatment

<b>Year 50 – Salvage Value</b>	
<b>None</b>	

### **SEC. 607.07 JOINTED CONCRETE PAVEMENT**

#### **CONSTRUCTION/RECONSTRUCTION WITH TIED PORTLAND CEMENT**

#### **CONCRETE SHOULDERS**

For most projects, a jointed concrete pavement with tied PCC shoulders is a viable construction or reconstruction option. Jointed concrete pavement can be constructed on a new alignment or on an existing alignment. If the existing pavement on an alignment is flexible, then the jointed concrete pavement can be constructed on top of it (if geometrically feasible). At the same time, unbonded jointed concrete pavement can be constructed on top of existing asphalt or concrete pavement. Such a treatment is typically comparable with reconstruction. Such pavement will follow the same maintenance cycles as that of a new jointed concrete pavement.

As with all pavement options, several criteria were established and assumptions made:

1. Initial pavement design life is 30 years.
2. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
3. The mill and replace is a fixed activity at Year 42 or at Year 45 (if SMA mix is utilized) in order to provide 10 or 13 (for SMA mixes) additional years of life to the pavement surface and structure.
4. The full-depth patching percentage for composite pavement is based on the pavement surface area.
5. The full-depth patching percentage for jointed concrete pavement is based on the pavement surface area.
6. PCC slab costs include the costs of tie bars, dowels, cut joints, and seal joints.

**Pavement Activities Table**

<b>Year 0 - New Construction/Reconstruction</b>	<b>Year 10 – Concrete Pavement Maintenance</b>
Mainline* Pavement Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Shoulders* Shoulder Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Soil Stabilization	Mainline Patching – 1.5% (of surface area) Clean and Seal Joint – 100%

\*As appropriate

<b>Year 20 – Concrete Pavement Restoration</b>	<b>Year 30 – Concrete Pavement Restoration and AC Overlay</b>
Mainline (Concrete Pavement Repair) Patching – 5% (of surface area) Clean and Seal Joints – 100% Grinding – 100%	Mainline Pre-overlay Repair: Patch – 5% (of surface area) AC Overlay (Minimum two lifts) with: AC Surface Material AC Intermediate Material AC Base Material Shoulders AC Overlay (Minimum two lifts) with: AC Wearing Course AC Intermediate Material AC Base Material

<b>Year 42 or 45* –Mill and Replace</b>	<b>Year 50 – Salvage Value</b>
Mainline Pre-overlay Repair Patching (AC overlay) - 2.5% (of surface area) Patching (PCC Base) – 2.5% (of surface area) Mill – Surface layer Replace with AC Intermediate Materials – one layer Overlay with AC Wearing Course – one layer Shoulders Overlay with AC Wearing Course – one layer	None

\*If SMA mixes utilized at year 30

**SEC. 607.08 JOINTED PLAIN CONCRETE PAVEMENT****CONSTRUCTION/RECONSTRUCTION WITH WIDE LANE (14 FEET) AND ASPHALT CONCRETE SHOULDERS**

For most projects, a jointed concrete pavement with wide lanes and AC shoulders is a viable construction or reconstruction option. Jointed concrete pavement can be constructed on a new alignment or an existing alignment. If the existing pavement on an alignment is flexible, then the jointed concrete pavement can be constructed on top of it (if geometrically feasible). At the same time, unbonded jointed concrete pavement can be constructed on top of existing asphalt or concrete pavement. Such a treatment is typically comparable with reconstruction. Such pavement will follow the same maintenance cycles as that of a new jointed concrete pavement.

As with all pavement options, several criteria were established and assumptions made:

1. The initial pavement design life is 30 years for the mainline. For the AC shoulders, the total thickness of the AC layers will be equal to the thickness of the mainline PCC slab.
2. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
3. The mill and replace is a fixed activity at Year 42 or at Year 45 (if SMA mixes are utilized) in order to provide 10 or 13 (for SMA mixes) additional years of life to the pavement surface and structure.
4. The full-depth patching percentage for composite pavement is based on the pavement surface area.
5. The full-depth patching percentage for jointed concrete pavement is based on the pavement surface area.
6. PCC slab costs include the costs of tie bars, dowels, cut joints, and seal joints.

**Pavement Activities Table**

<b>Year 0 - New Construction/Reconstruction</b>	<b>Year 10 – Concrete Pavement Maintenance</b>
Mainline with 14-Foot Lanes* – Inside and Outside Mainline Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Shoulders* Shoulder Removal (Reconstruction) AC Surface Material AC Intermediate Material AC Base Material CTA or DGA Subbase	Mainline Patching – 1.5% (of surface area) Clean and Seal Joint – 100% Shoulders Surface Treatment

<b>Year 0 - New Construction/Reconstruction</b>	<b>Year 10 – Concrete Pavement Maintenance</b>
Soil Stabilization	

\*As appropriate

<b>Year 20 – Concrete Pavement Restoration</b>	<b>Year 30 – Concrete Pavement Restoration and AC Overlay</b>
Mainline (Concrete Pavement Repair) Patching – 5% (of surface area) Clean and Seal Joints – 100% Grinding – 100% Shoulders Surface Treatment	Mainline Pre-overlay Repair: Patch – 5% (of surface area) AC Overlay (Minimum two lifts) with: AC Surface Material AC Intermediate Material AC Base Material Shoulders AC Overlay (Minimum two lifts) with: AC Wearing Course AC Intermediate Material AC Base Material

<b>Year 42 or 45*– Mill and Replace</b>	<b>Year 50 – Salvage Value</b>
Mainline Pre-overlay Repair Patching (AC overlay) - 2.5% (of surface area) Patching (PCC Base) – 2.5% (of surface area) Mill – Surface Course Replace with AC Intermediate Materials – one layer Overlay with AC Wearing Course – one layer Shoulders Overlay with AC Wearing Course – one layer	None

\*If SMA mixes utilized at year 30

**SEC. 607.09 CONTINUOUSLY REINFORCED CONCRETE PAVEMENT**  
**CONSTRUCTION/RECONSTRUCTION WITH TIED PORTLAND CEMENT**  
**CONCRETE SHOULDERS**

Continuously reinforced concrete pavement with tied PCC shoulders is a viable construction or reconstruction option. Continuously reinforced concrete pavement can be constructed on a new alignment or an existing alignment. If the existing pavement on an alignment is flexible, then the continuously reinforced concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

1. Initial pavement design life is 30 years.
2. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
3. The mill and replace is a fixed activity at Year 42 or at Year 45 (if SMA mix is utilized) in order to provide 10 or 13 (for SMA mixes) additional years of life to the pavement surface and structure.
4. The full-depth patching percentage for composite pavement is based on pavement surface area.
5. The full-depth patching percentage for continuously reinforced concrete pavement is based on surface area.

**Pavement Activities Table**

<b>Year 0 - New Construction/Reconstruction</b>	<b>Year 10 – Concrete Pavement Maintenance</b>
<b>Mainline*</b> Mainline Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase  <b>Shoulders*</b> Shoulder Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Soil Stabilization	<b>Mainline</b> Patching – 1% (of surface area) Clean and Seal Longitudinal Joint – 100%

\*As appropriate

<b>Year 20 – Concrete Pavement Restoration</b>	<b>Year 30 – Concrete Pavement Restoration and AC Overlay</b>
<b>Mainline (Concrete Pavement Repair)</b> Patching – 5% (of surface area) Clean and Seal Joints – 100% Grinding – 100%	<b>Mainline</b> Concrete Pavement Restoration: Patching – 5% (of surface area) AC Overlay with (typically two lifts): AC Wearing Course AC Intermediate or Base Material  <b>Shoulders</b> AC Overlay (typically two lifts) with: AC Wearing Course AC Intermediate or Base Material

<b>Year 42 or 45* –Mill and Replace</b>	<b>Year 50 – Salvage Value</b>
Mainline Patching (AC Overlay) – 2.5% Patching (PCC Base) – 2.5% Mill - Surface Course Replace with AC Wearing Course – one layer Shoulders Surface Treatment	None

\*If SMA mixes utilized at year 30

**SEC. 607.10 CONTINUOUSLY REINFORCED CONCRETE PAVEMENT**  
**CONSTRUCTION/RECONSTRUCTION WITH WIDE LANES (14 FEET) AND**  
**AC SHOULDERS**

Continuously reinforced concrete pavement with wide lanes and AC shoulders is a viable construction or reconstruction option. Continuously reinforced concrete pavement can be constructed on a new alignment or an existing alignment regardless of the existing pavement type. If the existing pavement on an alignment is flexible, then the continuously reinforced concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

1. Initial pavement design life is 30 years.
2. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
3. The mill and replace is a fixed activity at Year 42 or at Year 45 (if SMA mix is utilized) in order to provide 10 or 13 (for SMA mixes) additional years of life to the pavement surface and structure.
4. The full-depth patching percentage for composite pavement is based on pavement surface area.
5. The full-depth patching percentage for continuously reinforced concrete pavement is based on surface area.



**Pavement Activities Table**

<b>Year 0 – New Construction/Reconstruction</b>	<b>Year 10 – Concrete Pavement Maintenance</b>
Mainline with 14-Foot Lanes* – Outside and Inside Pavement Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Base  Shoulders* Shoulder Removal (Reconstruction) AC Surface Material AC Intermediate Material AC Base Material CTA or DGA Subbase Soil Stabilization	Mainline Patching – 1% (of surface area) Clean and Seal Joint – 100% Shoulders Surface Treatment

<b>Year 20 – Concrete Pavement Restoration</b>	<b>Year 30 – Concrete Pavement Restoration and AC Overlay</b>
Mainline (Concrete Pavement Repair) Patching – 5% Clean and Seal Joints – 100% Grinding – 100% Shoulders Surface Treatment	Mainline Concrete Pavement Restoration: Patching – 5% AC Overlay (typically two lifts) with: AC Wearing Course AC Intermediate or Base Material Shoulders AC Overlay (typically two lifts) with: AC Wearing Course AC Intermediate or Base Material

\*As appropriate

<b>Year 42 or 45* – Mill and Replace</b>	<b>Year 50 – Salvage Value</b>
Mainline Pre-overlay Repair Patching (AC Overlay) - 2.5% Patching (PCC Base) – 2.5% Mill - Surface course Replace with AC Surface Course – one layer Shoulders Surface Treatment	None

\*For SMA mixes

### **SEC. 607.11 LCCA FOR MAJOR REHABILITATION PROJECTS**

As stated in the Pavement Type Selection Procedures document (also Section 606 of Chapter VI of the MOI), multiple pavement types should be considered for major rehabilitation projects that meet certain length and structural criteria as described in that document. The rehabilitation design life for such projects must be at least 20 year. Pavement at this stage is significantly old and projection of service life for another 50 years is not realistic. For performing LCCA on major rehab projects, analysis period will be considered same as design life. The maintenance activity will be the same as those for the respective surface type up to the design life (not including any treatment necessary at the end of design life). For example, if the design life for major rehabilitation project is 20 years, the analysis period will also be 20 years. For AC option, overlay activities will be considered at year 15 (SMA mixes) and 12 (Superpave mixes). For PCC surface, concrete pavement maintenance will be conducted at year 10. However, CPR activity scheduled at year 20 will not be considered for LCCA since 20 year marks the end of analysis period in this case. If the design life for the competing options are different, Equivalent Uniform Annual Cost (EUAC) approach shall be used instead of Present Worth (PW) approach to accommodate the difference in design life. EUAC distributes the PW of the each option (initial cost plus any treatment cost during the design life) equally over the analysis period. The formula to compute both PW and EUAC are provided in section II of this document.

### **SEC. 607.12 UNIT COSTS AND MEASURES**

The life cycle cost for a pavement option is dependent on the corresponding activities required to construct and maintain the pavement. The cost for each activity is a function of unit cost and quantity measure. The following table provides units of measure. The measure is based on the Measurement and Payment Section in VDOT's *Road and Bridge Specifications* for each activity. The unit cost is based on historical and current costs to VDOT for similar or equivalent measures (i.e., quantities).

<b>Activity</b>	<b>Measure</b>
Milling/Planing	Square Yard – Inch
Fracturing PCC	Square Yard
AC Surface Material/Wearing Course	Tons
AC Intermediate Material	Tons
AC Base Material	Tons
Stabilized Drainage Layer	Tons
Pavement Demolition and Removal – Existing AC	Square Yard
Pavement Demolition and Removal – Existing PCC	Square Yard
Aggregate Subbase	Cubic Yard or Ton
Cement Treated Aggregate	Tons
Patching – CRCP	Square Yard
Patching – JPCP	Square Yard

Patching – AC	Tons
PCC Grinding	Square Yard
Joint Cleaning and Sealing	Linear Foot
CRCP	Square Yard
JPCP	Square Yard
Surface Treatment	Depends on Material Selected

### **SEC. 607.13 INTERPRETATION OF RESULTS**

Once the LCCA is completed for a project, the PW cost results must be interpreted. For new construction (new alignment and reconstruction) projects, if the PW values differ by more than 10 percent, the pavement type with the lowest present worth shall be recommended for final selection. If the PW values are within 10 percent, the project is a suitable candidate for alternate bidding process and the final selection of the pavement type will be made based on the bids received on two different pavement types.

For major rehab projects, if the PW values (or EUAC if applicable) differ by more than 10 percent, the pavement type with the lowest present worth shall be recommended for final selection. However, ancillary costs (like maintenance of traffic, guard rail etc.) should be taken into consideration before making the final selection. If the PW values (or EUAC if applicable) are within 10 percent, the engineer should consider all pavement options as economically feasible. If more than one pavement option is determined to be economically feasible, then factors such as the following must be considered before making the final selection.

- initial constructability
- constructability of future improvements
- volume of traffic
- maintenance of traffic
- climate
- recycling
- adjacent existing pavement (if applicable)
- traffic safety
- incorporation of experimental feature
- participating local government preference